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Rain Rate Monitoring and Flood Prediction Model

Project Report 2010 - 2011

by

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Abstract

The project involves monitoring of rain-rate from the degree of corresponding microwave attenuation, followed by prediction of time taken for a particular region to flood, given a particular rain-rate. The rain-rate measurement from microwave attenuation has been a known potential for many years. A comparison of several rain attenuation models has been demonstrated in detail. The rain-rate obtained from these relations is then integrated in a model which also takes in account the topography to predict the time required for the region to get flooded. The scope of the project is those cities which experience heavy rainfall and in turn suffer loss of life and property due to such rain floods. With this technique, it is possible to predict a impending flood. Also this method of prediction can be applied to any region, provided the necessary data is available.

Project Objective

The city of Mumbai experienced the worst floods in history on 26th July 2005 when it rained about 994 mm in 24 hours. Loss of life and property because of floods has now become a major issue. Hence it is necessary to monitor the rainfall in real time and consequently relay appropriate warnings in case of such events. However, there is no system in place at present which can perform these tasks. Thus, the objective of our project is to achieve these tasks.

The rain rate is monitored continuously with the help of corresponding microwave attenuation. This rain-rate thus calculated is used as one of the input parameters in a flood prediction model based on the concept of watersheds. In addition, the topography of a region also plays a crucial role in the time required for the region to get flooded. The system is faster and thus reduces the time required to relay warnings during rain floods and hence prevent significant damages.

The current prediction technique involves satellite imagery and traditional rain gauges. With the proposed technique, it is possible to monitor rain-rate in real time and reduce the prediction time. The prime objective therefore is to provide an additional aid to the Indian Meteorological Department. The system could be integrated with the existing techniques of flood prediction. Also the key users could include civil agencies at national, provincial/state and local level; military organization, corporations especially those which operate structures; voluntary emergency response organizations and the media.

Chapter 1

Introduction

Flooding is simultaneously one of nature's most destructive and violent forces. Floods occur when the flow of water exceeds the amount that can be contained in a river's natural banks or soil. This can happen due to a variety of factors, including rainfall intensity, duration, surface conditions, and the topography and slope of the receiving basin. The destructiveness of floods can also be exacerbated by many human activities, such as removing trees and vegetation, modifying the course of rivers and streams, and development in flood plain and urban areas. Such floods are a common phenomenon in many regions of the world and also a major form of natural disaster in many parts of the world. In the United States, where flood mitigation and prediction is advanced, floods do about $6 billion worth of damage and kill about 140 people every year. A 2007 report by the Organization for Economic Cooperation and Development found that coastal flooding alone does some $3 trillion in damage worldwide.

1.1 Need of the project:

The classical form of rain-related flood prediction involves use of traditional rain-gauges spread over a large area in addition to the satellite imagery and meteorological radars The density of rain gauges is not sufficient to cover whole area under consideration. Moreover the radars or other means used give only a synoptic view of the situation. Also the time taken for processing such information and hence relaying suitable warnings is too large. Hence need for a system that performs faster and has a shorter response time is crucial.

The rain gauges used at Indian Meteorological Department (IMD) are non-recording ones. The quantity of rainfall is measured every three hours. The data from these rain gauges is then utilized for further analysis purposes. Based on these measurements, the average rainfall of the day is calculated and recorded. This data along with cloud density from satellite imaging is used for weather forecasting. Non-recording rain gauges however give average intensity of rainfall and not the actual rainfall intensity. They record data only in three-hourly basis. The self recording ones are not automated to transmit in real time. In essence, the real time data is not available. Data has to be retrieved and scrutinized before it can be used in analysis. Hence after measurement of data, the result can be made available only after a couple of hours. Such a large window makes it difficult to predict the rainfall accurately. The IMD uses synoptic scale models for most of it predictions while certain concentrated rain events require meso-scale predictions.

1.2 26/7: What went wrong? Why the need for a area-wise prediction system?

According to the IMD's terminology for the classification of rainfall intensity, "Rather Heavy Rain" stands for 3.5 cm to 7.49 cm of rain over a 24 hour period, "Heavy Rain" for 7.5 cm to 12.49 cm and "Very Heavy Rain" for rain in excess of 12.5 cm. Clearly, the terminology is grossly inadequate to classify the unprecedented rain of July 26 in Mumbai. The meteorological station at Santacruz in North Mumbai recorded a whopping 94.4 cm of rain in 24 hours. Some pockets seem to have received even higher rainfall (Table 1). But, given the relative frequencies of rainfall with different intensity during the monsoon period, the terminology is not without logic. Table 2, for example, shows the relative frequencies for different rainfall intensity along the West Coast, where one witnesses spells of heavy rainfall during the monsoon.

Figure 1.1: Rainfall in different areas of Mumbai on July 26

1 Rainfall in different areas of Mumbai on July 26 (in cm)	
Colaba	7.34
Malabar Hill	7.40
Bhira	12.10
Dharavi	49.90
Santacruz	94.40
Bhandup	81.50
Vihar Lake	104.50
Tansa Lake	5.00

Historically, in more than a century of rainfall records of the IMD, the number of occasions Mumbai received more than 20 cm of rainfall in a day is 50; and, the number of occasions with more than 30 cm is only 13 (Table 3). The highest previously recorded day's rainfall in Mumbai is 57.56 cm on July 4, 1974. In fact, the July 26 rain in Mumbai was truly extraordinary even when compared with heaviest rainfall recorded in places such as Cherapunji (Table 4). But pertinently, in Mumbai's case the rainfall (and hence the scale of the weather system that caused it) was extremely localized. The station at Colaba in the southern end of Mumbai recorded only 7.34 cm of rain on the same day.

The extraordinary precipitation seems to have been spread across 20 to 30 km only. In meteorological parlance, processes that extend over such small scales (20 km to 200 km) are known as "mesoscale phenomena", as against "synoptic scale phenomena" (200 km to 2,000 km), on which the routine observational meteorology is based. Usually, "mesoscale phenomena" last for a very short duration (a few hours) while "synoptic scale phenomena" can last for a couple of days.

Given the available synoptic and modeling techniques, forecasting such a rare and extreme, and that too highly localized, event would seem to be nearly impossible. The techniques of synoptic or short range, forecasting (one to three days ahead) are based on the knowledge of events that occur with relatively high frequency. As Harold Brooks of the United States' National Oceanic and Atmospheric Administration (NOAA) points out: "Essentially, we're looking for ingredients to come together to produce such an extreme event and, in this case, they are unlikely to have been observed often enough to learn from them. We might be able to predict a very heavy (about 30 cm) event, but not the incredible event that occurred."

Even numerical weather prediction models require input data at appropriate spatial resolution (grid points) to be fed into the model as initial conditions. Roughly speaking, to analyze a complete wave of atmospheric disturbance any numerical model would require at least data at five grid points. Hence if the intrinsic resolution of a numerical weather prediction model is, say, 30 km (which would be a good model), the scale at which it can possibly predict processes or the formation of weather systems would be 120 km. Even for very high-resolution mesoscale forecasting models (say 5 km to 10 km resolution), it would be a tough ask to predict a phenomena on such a small scale as across 20 km.

In fact, given the meteorological systems that were developing in the days prior to the event, most models did predict heavy precipitation. But no model, at any forecasting centre of the world, could predict the extremely intense precipitation that occurred. Both the IMD, in its 24-hour forecast using a limited-area regional model, and the National Centre for Medium Range Weather Forecasting (NCMRWF), in its 48-hour forecast using a mesoscale model (with a 38 km resolution), had predicted 8cm to 16 cm of rain over Mumbai up to 8-30 a.m. of July 27.

Some models around the world, like the one at the United Kingdom Meteorological Office, apparently forecast up to 30 cm of rain. Even this, as the frequencies of intense rainfall events show, is of garden variety, and not anything unusual. However, according to Akhilesh Gupta of the NCMRWF, in a re-run of its model, with some improved input data assimilation techniques and changed input parameters (whose details are not known yet), the U.K. Meteorological Office found that its model predicted rainfall up to 80 cm. Notwithstanding this, it would be fair to say at this point of time that, given the paucity of wind and precipitation rate data, even the cause of the event (which is unlike any other in the past) is puzzling to say the least, though some speculations have been made.

Considering that the event was not amenable to prediction, the question that naturally arises is whether the people of Mumbai could have been forewarned, say a few hours ahead, of the impending disaster. For instance, the first warning, based on the local forecast for

Mumbai and suburbs, that the IMD sent out to all the agencies concerned on July 26, first at 1-00 p.m. and repeated thereafter, said: "Rather heavy to heavy rain accompanied by strong gusty winds likely in city and suburbs. Heavy rainfall likely to occur at a few places with very heavy rainfall at isolated places over Konkanpatti-Goa during next 48 hours. Heavy to very heavy rainfall likely to occur at isolated places over madhya [central] Maharashtra and Marathwada during the same period."

Given the classification of the intensity of rainfall, this warning hardly conveys the gravity of the developing situation. But with the observed rainfall at that time (about 1 cm of cumulative rain) and the limited instrumentation that is in place in the region, such a warning would seem natural and would have been considered appropriate by the IMD as well.

Figure 1.2: Percentage of days with rainfall above a given threshold along the western coast

2 Percentage of days with rainfall above a given threshold along the west coast*

Threshold cm per day	Percentage of days with rain above threshold
0.01	99.37
5.0	58.15
10	28.64
15	11.89
20	05.00
25	01.79
30	00.08

*Based on an M.Sc (Eng.) thesis by P.A. Francis, Indian Institute of Science (IISc), Bangalore, July 2002.

Francis analysed 100 intense rainfall events (above 20cm/day) using data from 30 met stations along the western coast during 1951-87. He found that there were 79 cases with maximum rainfall 20-30 cm/day, 13 cases with 30-40 cm/day, five cases with 40-50 cm/day and three cases above 50 cm/day and no event with above 60cm/day. Of the three cases above 50 cm/day, two were in Mumbai (Colaba) and one in Porbandar.

The instrumentation for weather-related measurements in Mumbai include manually operated rain gauges at variously located stations, whose data are recorded every three hours and transmitted, two continuous self-recording rain gauges at Colaba and Santacruz meteorological stations, and an X-band weather radar. The radar is basically a wind-and-storm detection instrument which can, at best, be used to detect cloudiness and measure size and depth of clouds.

If an S-band Doppler weather radar or radars (with a range of about 300 km) had been in place, one would have got wind speeds of the rapid convection systems that were continuously feeding high levels of moisture into the clouds in a localized fashion and the high precipitation rates. Such a radar would have been able to show not only how much rain had fallen and the rate at which it had fallen, but also the extent of rain that was approaching the area hours ahead. However, while any such system would have probably warned of a rainfall intensity of 30 cm to 50 cm, a rainfall intensity of above 90 cm could not have been anticipated at all given the history of intense rainfall events in the region. But the event has certainly brought home the urgency to implement the proposed Doppler Weather Radar (DWR) network along coastal India. It would also perhaps call for a rethink on the density of the network along the western coast. Unlike the network on the east for cyclone detection, a fewer number have been proposed along the west.

There was a rapid increase in the rate of precipitation at the Santacruz meteorological station. In the three-hour duration between 2-30 p.m. and 5-30 p.m. on July 26, it poured nearly 39 cm; more rain per hour than a full day's rain in many intense rainfall days during monsoon. Unfortunately, the instrumentation network of the IMD that is in place does not provide real-time data online. While the manually operated rain gauges give data only in three-hourly bins, the self-recording ones are not automated to transmit in real-time. The data has to be retrieved and scrutinized before it can be used in analysis.

3 History of heavy rainfall days in Mumbai	
Colaba (South Mumbai 18.9° N)	
Number of occasions with more than 20 cm/day rainfall	50
Number of occasions with more than 30 cm/day rainfall	13
Very intense rainfall events in the past:	
Above 50 cm on September 9, 1930	
57.56 cm on July 4, 1974	
54.43 cm on July 1, 1984	
Santacruz Station (North Mumbai 19.05° N)	
Number of occasions with more than 20 cm/day rainfall	37
Number of occasions with more than 30 cm/day rainfall	11
Very intense rainfall events in the past:	
39.9 cm on June 10, 1991	

Figure 1.3: Fig 1:History of heavy rainfall days in Mumbai

However, given the intense rainfall along Goa and coastal Karnataka in the preceding days, and given the sudden cloudburst-like activity in Mumbai, the meteorological officials should have responded to the situation better and obtained the rain gauge data more frequently, say on a half-hourly or hourly basis. The first half-hour in the beginning of the next three-hourly bin (2-30 p.m. to 5-30 p.m.) itself would have indicated the extreme nature of the event. That would have probably sufficed to issue an immediate red alert following the earlier warning. But this was not done and a couple of crucial hours were perhaps lost. In fact, the sad part is that till date, data from the continuous self-recording rain gauges are not available even to the IMD headquarters in Delhi for a proper diagnosis of the event both by the IMD and other researchers across the country.

Figure 1.4: Extraordinarily heavy rainfall events over India

4 Extraordinarily heavy rainfall events over India (cm/24hours)		
May 6, 2004	Amini Devi	116.8
June 14, 1876	Cherapunji	103.6
July 10, 1912	Cherapunji	99.8
June 18, 1899	Kasauli	99.6
July 10, 1952	Mowsimram	98.9
July 2, 1941	Dharampur	98.7
September 13, 1974	Cherapunji	98.5
July 27, 2005	Santacruz	94.4

1.3 Scope of the Project:

The purpose of the project is to put forth an efficient system for predicting floods. The basic prediction is based on forecasting the time required for a particular region to flood based on its topography and the corresponding rain-rate. In addition the use of microwave attenuation to predict the corresponding rain-rate has been proposed. There exists a relation between microwave attenuation and rain-rate proposed by the ITU-R. However some observations have shown that this relation does not clearly define the conditions prevailing in the tropical regions. In addition an analysis was done for the same by the mobile service provider Orange in the year 2010 .The project provides a detailed analysis of these relations and some related observation.

The core model takes two primary inputs namely: rain-rate and topography of an area. For the purpose of the analysis a small region consisting of the Andheri, Vile Parle and Jogeshwari areas in Mumbai. It forecasts the time required for a particular area to flood taking into account the basic consideration that low-lying areas get flooded faster than those relatively higher than the sea-level. The flood prediction should take into account a wide range of factors such as the soil characteristics, the nature of soil et cetera. However the effects of these parameters have not been accounted for due to lack of sufficient data.

The model provides satisfactory results for flood prediction and can be expanded to include more parameters and give more accurate results. With the inclusion of a variety of factors and parameters an elaborate flood prediction system can be designed.

Chapter 2

Literature Survey

This chapter includes the summary of all the papers referred and studied for the implementation of the project.

2.1 Monitoring Rain Rate with Data from Networks of Microwave Transmission Links - Christian Mtzler, Ernest Koffi and Alexis Berne

Monitoring microwave attenuation (20 to 45 GHz) of directional transmission links is a method to derive rain rate at high time resolution and in near-real time. Raindrops falling through a propagation path of a microwave link attenuate the transmitted signal quasi linearly with rain rate, allowing the estimation of path-averaged rain intensity. These data are valuable for meteorology, hydrology, agriculture, flood control, and others. The application to entire networks of commercial links would be a cost-effective method to fill data gaps where precipitation-radar data are either distorted or missing, such as large cities, valleys in mountain areas and developing countries.

Regionally representative rain information is needed in many areas, such as now-casting, assimilation into numerical weather prediction models, hydropower, agriculture, flood control, traffic safety, pollution control, and for the validation of remote-sensing methods. The information would contribute to the reduction of socio-economic impacts of heavy rains related to flood hazards. The classical rain observation uses rain gauges, which integrate rain rate over time at single points. Wind is known to cause systematic errors. Widespread is the use of precipitation radar giving a synoptic view of the rain dynamics over large areas, but due to disturbing effects, the estimation of areal rain amount appears to be less accurate than from the rain gauges. Rainfall estimation from microwave links has been a known potential for many years. The results of past investigations showed that the extinction of radiation in the frequency around 30 GHz by rain is quasi-linearly related to rain-rate, and the relation is nearly independent of the drop size distribution. As a consequence attenuation data at a suitable frequency are excellent to retrieve path-averaged rain rate.[1]

Extended networks of microwave links have been set up in almost all countries. Therefore the implementation of the proposed method is especially valuable in regions, which lack full radar coverage. The method is cost effective because the infrastructure exists already. The main difficulties encountered so far are, on the one hand, an insufficient time resolution of the attenuation measurements of the operating software used to run and control the links.

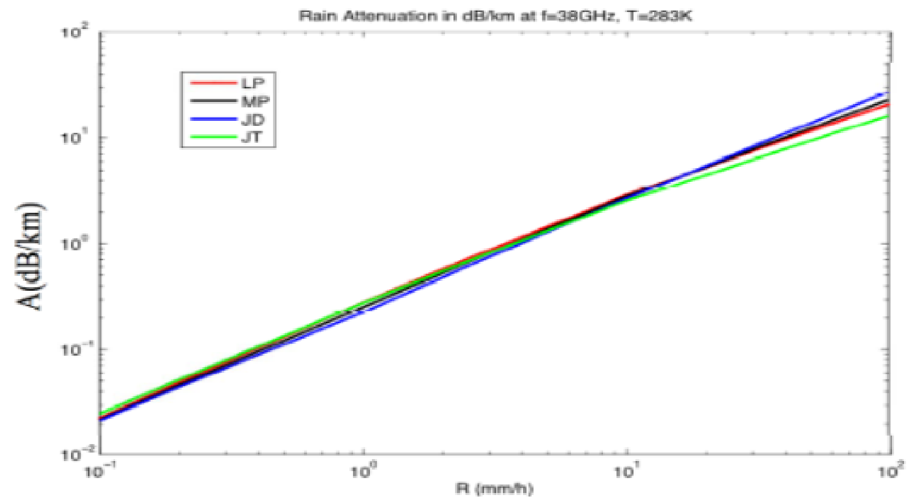


Figure 2.1: Extinction coefficient A in dB/km at 38 GHz of rain at a temperature T=283K versus rain rate R in mm/h for the four drop-size distributions

Areal and quantitative information on rain is urgently needed for sustainable developments and for a wide range of human activities. Global change and increasing population will even enhance the urgency in future. The use of networks of microwave transmission links has been identified as an accurate method to satisfy these needs. Commercial links, especially at 38 GHz are near optimal and most abundant, and they should be adapted to extract path-loss information in near-real time. An essential advantage of the method is the availability of suitable links in almost all countries, including large regions without access to precipitation radar.

2.2 Cumulative distributions of rainfall rate and microwave attenuation in Singapore's tropical region - Z. X. Zhou, L. W. Li, T. S. Yeo, and M. S. Leong

The microwave attenuation due to rainfall in tropical regions has not been very widely studied yet. In Singapore's tropical environment, line-of-sight microwave communication links were set up and have been operated for several years to study the microwave attenuation characteristics due to tropical rainfall. In this paper the experimental results are presented, including the relationship between specific attenuation and rainfall rate. The results show that the rainfall rate and the microwave propagation characteristics in Singapore over a 10-month experiment period are out of accord with International Radio Consultative Committee predictions.

With the increasing requirement and establishment of more and more communications systems, it becomes necessary to study the microwave attenuation due to rainfall in various climatic zones. There exists a lot of research carried out in several countries, such as America, Europe, and Japan, on the microwave propagation characteristics. The results published in the literature are mainly applicable to regions of higher latitude, whereas the results available for the tropical regions are quite limited. When the International Radio Consultative Committee (CCIR) recommended model is applied to the tropical regions, the inaccuracies of these empirical formulae are clearly seen.[2]

To study the microwave propagation characteristics, experiments have been carried out in Singapore. Previously published articles have introduced the setup of the experiment, analyzed the microwave attenuation due to rainfall at 21.225 GHz, proposed the cumulative distributions of attenuation and attenuation duration at frequencies of 15 and 38.6 GHz, and also obtained the frequency scaling empirical formulae. As described previously, the experimental results obtained in Singapore differ a lot from the CCIR predictions. In accord with the CCIR recommendations, these experimental results are carefully studied again, and the empirical formulae are proposed according to CCIR recommendations.

2.2.1 Comparisons of experimental and CCIR predictions

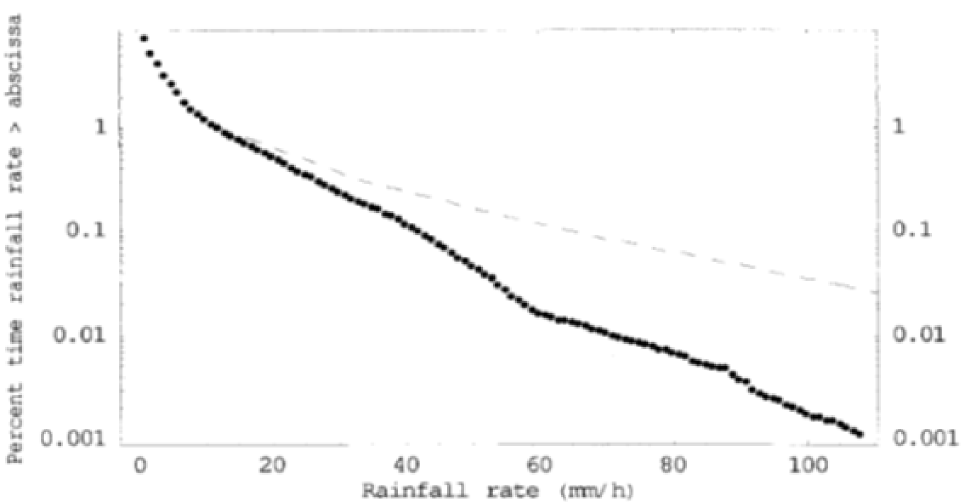


Figure 2.2: Cumulative distribution of rainfall rate in Singapore compared with the International Radio Consultative Committee (CCIR) prediction

The dashed line is rainfall rate cumulative distribution predicted by CCIR; the dotted line is that of measurement during experiment period of 10 months.

The top and bottom solid curves stand for best fit relationship between specific attenuation and rainfall rate for 38.6 and 15 GHz, respectively, with the dots denoting measured data. The top and bottom dashed curves are those from CCIR predictions for 38.6 and 15 GHz, respectively.

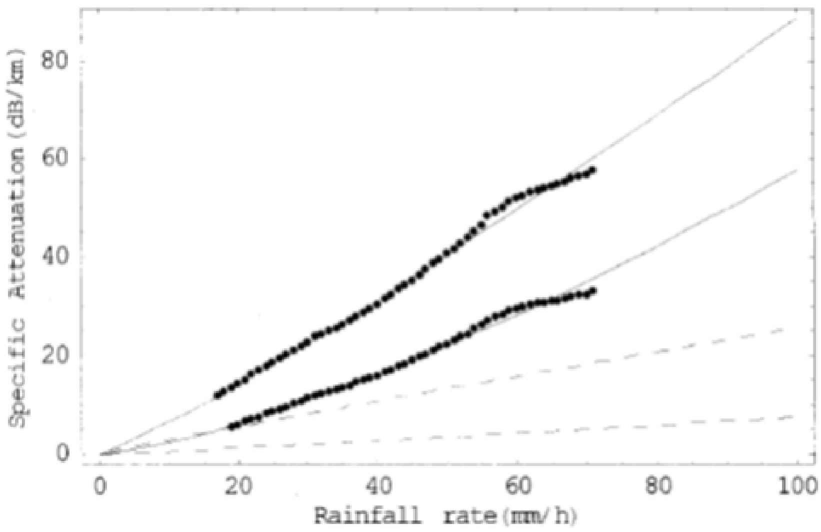


Figure 2.3: Relationship between attenuation and rainfall rate compared with that of the CCIR at frequencies of 15 and 38.6 GHz.

It is seen that for the 10-month experiment period, the 1-min average rainfall rate distribution is much different from the CCIR predictions for Singapore's tropical environment. It is again confirmed that the CCIR recommendations have underestimated the microwave specific attenuation due to tropical rainfall at least in the 10-month-term view. This needs to be studied further. The frequency scaling formula in Singapore in the experiment period is also out of accord with those in literature, and it seems to follow a square root law in the frequency range from 10 to 40 GHz. In summation, in our 10-month experiment period, the rainfall rate is much smaller than predicted by CCIR for the same percent time (for example, 0.01%), while the specific attenuation is much bigger than that predicted by CCIR. It has been proposed that the raindrop model and raindrop size distribution in Singapore are quite different from those adopted by CCIR.

2.3 Rain Attenuation Measurements in Amritsar over terrestrial microwave link at 19.4 & 28.75 GHz - Ashok Kumar, I. S. Hudiara, Sarita Sharma And Vibhu Sharma

Rain induced attenuation at 19.4 & 28.75 GHz over a terrestrial path link of 2.29 km was measured for the period of one year in Amritsar $(31 \deg 36 \deg N 74 \deg 52 \deg E)$ environment. An empirical model for predicting rain-induced attenuation on terrestrial path link is proposed. Measured prediction has been compared with the recently prediction method proposed by the International Telecommunication union (ITU-R). It appears that the prediction found differ from those predicted by ITU-R equation for the rain rate encountered in this period.

System setup for the rain attenuation measurement is shown in the figure. This arrangement provides a dynamic range of about 45 dB at 19.4 GHz and about 47 dB at 28.75 of excess attenuation, which is adequate for our purpose.[3]

Figure 2.4: The measured and ITU-R rain rate

% time rain rate exceeded	Measured (mm/hr)	ITU-R 'L'
0.001	110.5	150
0.003	88.5	105
0.01	62	60
0.03	39.70	33
0.05	29.5	24
0.08	16.3	17
0.1	12.6	15
0.3	2	7
0.5	0.75	2

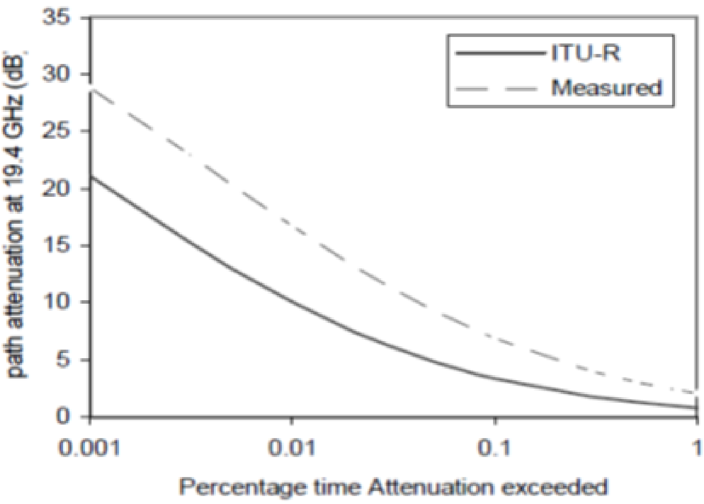


Figure 2.5: Annual cumulative percentage of time for path attenuation exceeding present level

The results of one-year measurement of rain attenuation of microwave signal propagating at 19.4 & 28.75 GHz have been presented. The annual statistics of rainfall rate and rain attenuation have been derived from the measured experimental data and compared with those predicted by ITU-R. It is observed that ITU-R predictions underestimate the measured rainfall rate and rain attenuation statistics.

2.4 Monitoring of rainfall by ground-based passive microwave systems:Models, measurements and applications - F. S. Marzano, D. Cimini, and R. Ware

A large set of ground-based multi-frequency microwave radiometric simulations and measurements during different precipitation regimes are analyzed. Simulations are performed for a

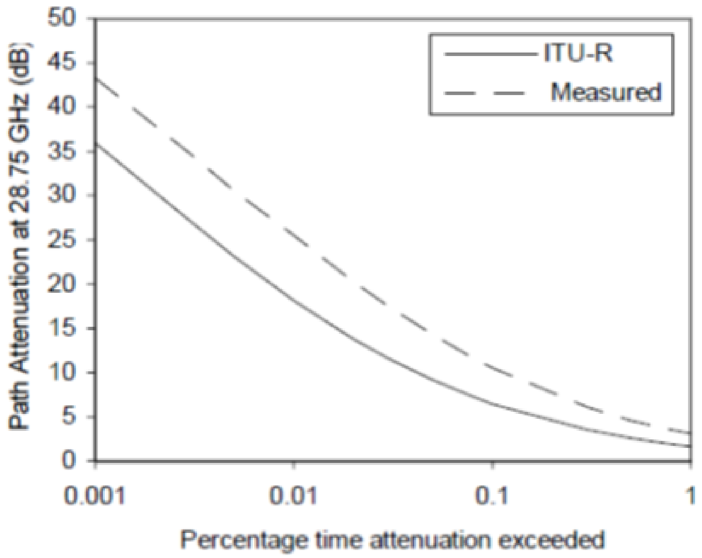


Figure 2.6: Annual cumulative percentage of time for path attenuation exceeding preset level

set of frequencies from 22 to 60 GHz, representing the channels currently available on an operational ground-based radiometric system. Results are illustrated in terms of comparisons between measurements and model data in order to show that the observed radiometric signatures can be attributed to rainfall scattering and absorption. An inversion algorithm has been developed, basing on the simulated data, to retrieve rain rate from passive radiometric observations.

Ground-based microwave radiometry has been mainly investigated for estimating temperature, water vapor and cloud liquid profiles in the absence of precipitation. However, the increasing use of multi-frequency radiometers in ground-based stations has raised the question of their potential for retrieving also rainfall rate from ground. From an experimental point of view, one of the main problems of ground-based radiometry for rainfall retrieval is the possible impact of water layers on the receiving antenna whose measurements can be heavily contaminated, From a modeling point of view, the approach to rainfall signature characterization requests a thorough insight into the electromagnetic interaction between the microwave radiation and the scattering medium. The radiative transfer theory has been so far the most used approach to take into account multiple scattering and vertical in homogeneity of the atmosphere in the presence of hydrometeor scattering.

The objective of this paper is to investigate about the rainfall signature on multispectral microwave measurements from ground. An inversion algorithm for ground-based retrieval of surface rain-rate is developed. Simulation results are shown to illustrate the potential of the proposed models by selecting a set of frequencies from 22 to 60 GHz, representing the channels currently available on a operational ground-based radiometric system. The latter instrument has been recently upgraded to minimize the effects of hydrometeors on the radiometric measurements, a circumstance experimentally proved as well.

On analysis of a large set of ground-based multi-frequency radiometric measurements and simulations for different precipitation regimes. The modeled frequencies have been selected in order to match the set of channels currently available on an operational ground-based radiometric system. Rain events occurred in Boulder, Colorado and at the ARM SGP site have been analyzed in terms of comparisons between measurements and model data. This comparison has in a way validated that the observed radiometric signatures can be attributed to rainfall scattering and absorption.[4]

2.5 Rain Attenuation Modeling In The 10-100 GHz Frequency Using Drop Size Distributions For Different Climatic Zones In Tropical India - S. Das, A. Maitra, A. K. Shukla

Rain drop size distributions (DSD) are measured with disdrometers at five different climatic locations in the Indian tropical region. The distribution of drop size is assumed to be lognormal to model the rain attenuation in the frequency range of 10-100 GHz. The rain attenuation is estimated assuming single scattering of spherical rain drops. Different attenuation characteristics are observed for different regions due to the dependency of DSD on climatic conditions. A comparison shows that significant differences between ITU-R model and DSD derived values occur at high frequency and at high rain rates for different regions. At frequencies below 30 GHz, the ITU-R model matches well with the DSD generated values up to 30mm/h rain rate but differ above that. The results will be helpful in understanding the pattern of rain attenuation variation and designing the systems at EHF bands in the tropical region. Rain attenuation is a major limiting factor above 10 GHz frequency bands to be used in radio communications. Rain attenuation modeling is usually done in terms of drop size distribution (DSD). But, the variability of DSD for different climatic regions is a major concern, especially for the tropical region, which has a huge diversity in climatic conditions. In the absence of measured attenuation data, DSD measurements can provide useful information on the variation of the rain attenuation. Rain DSD varies with rain rate as well with the location. Thus the same rain rate can correspond to different DSDs. Raindrop size distributions depend on several factors such as rainfall intensity, circulation system, type of precipitation, wind share, cloud type, etc. It is thus very difficult to formulate a single DSD model to describe the actual raindrop size distribution for all location and rain type.DSD is normally modeled with distributions like exponential, gamma and lognormal.

The lognormal distribution is more suited for the lower end of drop spectrum due to its steeper gradient than the gamma distribution. From the various studies over tropical region, it is found that three-parameter lognormal model is suitable for this region. Therefore, in the present study, lognormal model is considered to be the representative distribution for DSD. Currently, Indian Space Research Organization (ISRO), as a part of earth-space propagation experiment over India region conducting ground based measurements at five different geographical locations, namely, Ahmedabad(AHM), Shillong(SHL), Trivandrum(TVM), Kharagpur(KGP) and Hassan(HAS). These locations fall in different climatic zones of India with different rain characteristics. In the absence of actual earth-space propagation measurements, the attenuation modeling using DSD is attempted. This study will be helpful for understanding the rain attenuation characteristics over the Indian tropical region.

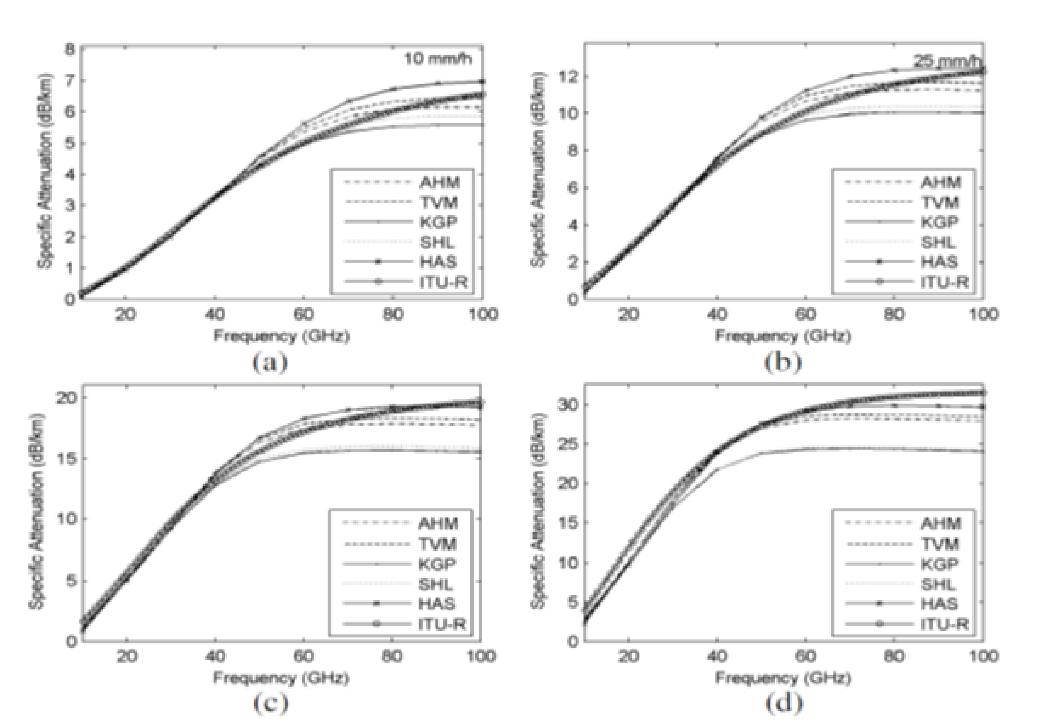


Figure 2.7: Specific attenuation for different locations with frequency a rain rate (a) 10 mm/h, (b) 25 mm/h, (c) 50mm/h and (d) 100 mm/h.

The DSD modeling in terms of lognormal function has been carried out to estimate the rain attenuation at different places in Indian region in the frequency range of 10-100 GHz. Results show that there is a strong variability of specific rain attenuation at different locations at higher rain rates. DSD is found to depend strongly upon local climate of the different locations in the Indian region. It also comes out from the analysis that the ITU-R model overestimates rain attenuation at frequencies above 30 GHz at all rain rates over the Indian region.[5]

2.6 Inference

The microwave attenuation varies linearly with the rain-rate. In the tropical regions however this relation does not hold entirely true due to variation in the drop-size distribution. This case was supported by the paper based on studies carried out in Amritsar. Hence, it is necessary to modify the existing relations to suit the conditions in tropical regions.

Chapter 3

Basics of Rainfall Measurements

Rainfall measurement involves a number of parameters. These parameters along with relevant concepts and some apparatuses for rainfall measurement are illustrated in this chapter.

3.1 Rain Fall Intensity:

The intensity of rainfall is the rate at which the rain is falling and it is expressed in cm/hr. For example, during a particular event of rainfall occurred for 10 minutes and the quantity of rainfall is 2 cm, then the intensity of rainfall of that rain event is 12 cm/hr. 5 cm/ hr intensity of rainfall means an average rainfall rate of 5 cm per hour duration. The rainfall particulars are recorded with either non-recording rain gauges or automatic recording rain gauges or by Meteorological Department (IMD).

3.2 Rainfall Recording

3.2.1 Non-recording Gauges

In non-recording gauges the rainfall for the past 24 h is measured and recorded as cm of rainfall during the last 24 hours. These data give only average intensity and not the actual intensity of rainfall of the rain event, which might have last for only 10 to 15 minutes. These types of rain gauges do not record the rain but only collect the rain. Symons's type instrument is most commonly used. The rain gauge consists of a collector, with a gun metal rim, a base and a polythene bottle. The collector and the base are made of Fiber Glass Reinforced (FRP). The collectors have aperture of either 100 cm2 or 200 cm2 area and are so made that they are interchangeable. The polythene bottles are of three sizes having capacities of 2, 4 and 10 liters of water respectively. The rain gauge should be fixed on a masonry or concrete foundation 60 x 60 x 60 cm sunk into the ground. The base of the gauge should be embedded in the foundation, so that the rim of the gauge is exactly 30 cm above the surrounding ground level. The rim of the gauge should be kept perfectly level. The horizontality should be checked with a spirit level laid across the rim.

At the time of recording rainfall, the funnel of the rain gauge is removed and the polythene bottle taken out. The measuring jar is placed in an empty basin and the contents are poured slowly out of the receiver into the measuring jar taking care to avoid spilling. If, however, any water is spilled into the basin, its amount to the water in the measuring jar before arriving at the total amount collected. While reading the amount of rain, the measuring jar is held, upright between the thumb and the first finger or placed it on a table or other horizontal surface. The eye is brought to the level of the water in the measure glass and the reading of the bottom of the meniscus or curved surface of the water is taken. The amount of rainfall should be read in millimeters and tenths. It is extremely important to note that the correct type of measuring jar appropriate to the type of rain gauge funnel in use should be used for measuring the amount of rainfall, to avoid errors in the results. A value of 0.0 is entered for no rain and a 't' (meaning trace) for rainfall below 0.1 mm.

The collector of the rain gauge, the receiving bottle and measuring cylinder are always kept clean. They should be emptied regularly of sediment or other material that may have fallen into them and cleaned periodically. The grass around the gauge should be kept short. No shrubs or plants should be allowed to grow around the gauge.

3.2.2 Automatic Recording Gauges

Automatic rain gauges record continuously the cumulative amount of water with time on a graph paper. After the collection in the bottle has recorded 10 mm of rain, the bottle gets emptied and the line representing cumulative rainfall vertically falls down. Hence, while estimating the amount of rain fallen during any time interval, this fact must be kept in view. The graph of the automatic rain gauge shows the time taken for each 10 mm of rain. The total rainfall in any particular hour can be obtained from the graph.

Recording type of rain gauges are those which can give a permanent automatic rainfall record without bottle reading. In this type of rain gauges, a man need not go to the gauge to measure or read the amount of rain fallen. A mechanical arrangement by which the total amount of rain fallen, since the record was started, gets recorded automatically in graph paper. Thus the gauge forms a record of cumulative rain versus time in the form of a graph and which is known as the mass curve of rain fallen. The curve also helps in indicating the times of onset and cessation of a rain and its duration. The slope of the curve gives the intensity of rainfall for any given period.

Since such gauge represent the cumulative rain, they are called as integrating rain gauges. There are three types of recording rain gauges. They are:

- Tipping Bucket Gauge In this type of rain gauge, the rainwater is collected in the collector and then passed through a funnel. The funnel discharges the water into a two compartment bucket. If 0.1mm of rainwater gets filled up in one compartment, the bucket tips emptying in to a reservoir and moving the second compartment into place beneath the funnel. The tipping bucket completes an electric circuit, causing a pen to mark on a revolving drum. These types of gauges are generally in hilly and inaccessible areas, where they can supply measurements directly to control room. No graph paper or drum is installed in the gauge and the rainfall measurements are directly recorded at the control room.

- Weighting Type This type of gauge weights the rain which falls into a bucket placed on the platform of a spring or a lever balance or any other weighting mechanisms .When the weight of the bucket increases that helps in recording the increased quantity of rain with time by moving a pen on a revolving drum.

- Floating Type In this type of gauge, the rise of floating body due to increasing rain catch helps in lifting the pen point, which goes on recording the cumulative rain with time in a graph paper wrapped round a rotating drum. Nowadays various types of floating type recording rain gauges are available. Natural Siphon recording rain gauge is widely used in India.

The rainwater entering the gauge at the top of the cover is led via the funnel to the receiver, consisting of a float chamber and a siphon chamber. A pen is mounted on the stem of the float, and as the water level in the receiver rises, the float arises and the pen records, on a chart wrapped round a clockwise rotating drum, the amount of water in the receiver at any instant. The rotating drum completes one revolution in 24 hours (one day) or sometimes in 7 days. Siphoning occurs automatically when the pen reaches the top of the chart, and as the rain continues, the pen rises again from the zero line of the chart. If there is no rain, the pen traces a horizontal line from where it leaves off rising.

The siphon recording rain gauge is an instrument designed for continuous recording of rainfall. In addition to the total amount of rainfall, the onset and cessation of rain (and therefore the duration of rainfall) are recorded.

The gauge should be installed in such a way that the rim of the funnel is horizontal and set at a height of exactly 75 cm above ground level. For setting the pen at the zero mark, pour sufficient water into the receiver till the pen reaches the top and water siphons out. After all the water is drained out, the pen should be on the zero line; if not, it should be adjusted.

Rainfall enters the gauge at the top via a funnel and passes through a receiver consisting of a float chamber and a siphon chamber. A pen is mounted on the stem of the float, and as the water level rises in the receiver, the float rises and the pen records the level of water in the chamber on a chart wrapped round a clockwise rotating drum. The rotating drum completes one revolution in 24 hours (one day) or sometimes in 7 days. Siphoning occurs automatically when the pen reaches the top of the chart, at the 10 mm mark, and then the pen comes down to the zero line of the chart. The pen rises again with the onset of rainfall. When there is no rain, the pen traces a base horizontal line of the chart.

The siphon is arranged concentrically so that the long discharge tube being surrounded by the shorter siphon chamber and is directly connected to the float chamber. A glass piece is placed over the joint of these tubes and the passage connecting two tubes at this joint is of almost capillary dimensions, but the sectional area is large enough to discharge the water collected in the receiver with enough speed. When the upper end of the water level falls to a certain depth, the siphon ceases to act, the water column is broken at a definite stage by a bubble of air which gets into the capillary and freedom from dribbling is thus ensured. There is just sufficient water to float the float after siphoning.

The chart should be changed daily (in India at 08 30 IST) as a routine observation irrespective of the rainfall occurrence. The observer should see that the pen trace matches the base horizontal line of the chart without an error after every siphoning operation. The instrument should be checked daily once for correct siphoning operation.

3.3 Duration of Rainfall

The duration of rainfall is the time period for which the rain event occurs at that given intensity of rainfall. From the historic records of the automatic rain gauge station (of graphs) for 30 to 50 years the intensity of rainfalls for different time intervals such as 5 minutes, 10 minutes, 15 minutes, 20 minutes, 60 minutes, etc., could be obtained.

3.4 Frequency of Rainfall

The frequency of rainfall is the number of times the rainfall of a particular intensity and duration occurred in the past based on the historic records. Frequency of rainfall is also known as the recurrence interval of a particular rainfall.

3.5 The Watershed Concept

A watershed can be defined as the area of land that drains to a particular point along a stream. Each stream has its own watershed. Topography is the key element affecting this area of land. The boundary of a watershed is defined by the highest elevations surrounding the stream. A drop of water falling outside of the boundary will drain to another watershed.

Figure 3.1: Watershed

A watershed is an area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel. The word watershed is sometimes used interchangeably with drainage basin or catchment. Ridges and hills that separate two watersheds are called the drainage divide. The watershed consists of surface water–lakes, streams, reservoirs, and wetlands–and all the underlying ground water. Larger watersheds contain many smaller watersheds. It all depends on the outflow point; all of the land that drains water to the outflow point is the watershed for that outflow location. Watersheds are important because the stream-flow and the water quality of a river are affected by things, human-induced or not, happening in the land area "above" the river-outflow point.

3.5.1 A watershed is a precipitation collector

Most of the precipitation that falls within the drainage area of a stream's monitoring site collects in the stream and eventually flows by the monitoring site. Many factors, some listed below, determine how much of the streamflow will flow by the monitoring site. Imagine that the whole basin is covered with a big (and strong) plastic sheet. Then if it rained one inch, all of that rain would fall on the plastic, run down-slope into gulleys and small creeks and then drain into main stream. Ignoring evaporation and any other losses, and using a 1-square mile example watershed, then all of the approximately 17,378,560 gallons of water that fell as rainfall would eventually flow by the watershed-outflow point.

3.5.2 Not all precipitation that falls in a watershed flows out

To picture a watershed as a plastic-covered area of land that collects precipitation is overly simplistic and not at all like a real-world watershed. A career could be built on trying to model a watershed water budget (correlating water coming into a watershed to water leaving a watershed). There are many factors that determine how much water flows in a stream (these factors are universal in nature and not particular to a single stream):

Precipitation:

The greatest factor controlling stream-flow, by far, is the amount of precipitation that falls in the watershed as rain or snow. However, not all precipitation that falls in a watershed flows out, and a stream will often continue to flow where there is no direct runoff from recent precipitation.

Infiltration:

When rain falls on dry ground, some of the water soaks in, or infiltrates the soil. Some water that infiltrates will remain in the shallow soil layer, where it will gradually move downhill, through the soil, and eventually enters the stream by seepage into the stream bank. Some of the water may infiltrate much deeper, recharging ground-water aquifers. Water may travel long distances or remain in storage for long periods before returning to the surface. The amount of water that will soak in over time depends on several characteristics of the watershed:

- Soil characteristics: In Georgia, clayey and rocky soils of the northern areas absorb less water at a slower rate than sandy soils, such as in Georgia's Coastal Plain. Soils absorbing less water results in more runoff overland into streams.

- Soil saturation: Like a wet sponge, soil already saturated from previous rainfall can't absorb much more ... thus more rainfall will become surface runoff.

- Land cover: Some land covers have a great impact on infiltration and rainfall runoff. Impervious surfaces, such as parking lots, roads, and developments, act as a "fast lane" for rainfall - right into storm drains that drain directly into streams. Flooding becomes more prevalent as the area of impervious surfaces increase.

- Slope of the land: Water falling on steeply-sloped land runs off more quickly than water falling on flat land.[1]

Chapter 4

Rain Attenuation and Now-casting

Rain attenuation corresponds to degradation of microwave signal due to rainfall. It is possible to use this attenuation in turn to predict rainfall rate. This rainfall has been used to predict the time in which a particular region will get flooded, given a particular rain rate. The process of prediction whereby we get results a short time after we input parameters is known as now-casting.

4.1 Microwave attenuation to predict rain-rate

The measurement of rainfall in urban areas is important both for design of urban drainage systems and rainfall forecasting as input to urban drainage models (udm) to operate and control drainage systems in real-time. In addition flood warning aspects have become important in recent years. At present, rainfall as input to urban drainage models is deduced from the measurement made by rain-gauges whereas the use of radar data in urban drainage model is neither a new task nor a common practice

The classical rain observation uses rain gauges, which integrate rain rate over time at single points. Gauges measure single point rainfall and therefore their spatial significance is limited. Particularly in convective storms a series of point measurements may give a poor reflection of the areal rainfall in the catchment. Wind is known to cause systematic errors. Widespread is the use of precipitation radar giving a synoptic view of the rain dynamics over large areas, but due to disturbing effects, the estimation of areal rain amount appears to be less accurate. Even though the problems connected with this measurement method, like clutter, attenuation and Z/R relation, have to be taken care of, radar data provide valuable information in real time control applications.

Monitoring microwave attenuation of directional transmission links is a method to derive rain rate at high time resolution and in near-real time. Raindrops falling through a propagation path of a microwave link attenuate the transmitted signal quasi linearly with rain rate, allowing the estimation of path-averaged rain intensity. These data are valuable for meteorology, hydrology, agriculture, flood control, and others. The application to entire networks of commercial links would be a cost-effective method to fill data gaps where precipitation-radar data are either distorted or missing, such as large cities, valleys in mountain areas and developing countries. Regionally representative rain information is needed in many areas, such as now-casting, assimilation into numerical weather prediction models, hydropower, agriculture, flood control, traffic safety, pollution control, and for the validation of remote-sensing methods. The information would contribute to the reduction of socio-economic impacts of heavy rains related to flood hazards. With climate change, storms may become more frequent and more severe, and thus such information will become even more important.

Rainfall estimation from microwave links has been a known potential for many years, but a breakthrough to operational applications is still lacking. The results of past investigations showed that the extinction of radiation in the frequency around 30 GHz by rain is quasi-linearly related to rain rate, and the relation is nearly independent of the drop-size distribution As a consequence attenuation data at a suitable frequency are excellent to retrieve path-averaged rain rate. Such data would be representative for a real precipitation. The use of commercial hardware installations however poses new challenges, because commercial microwave networks are optimized for high communication performance and are designed in the way that reduces the effect of weather-related impairments on quality of service. Thus, the observation type, time and magnitude resolution, network geometry and frequencies are predefined and, in most cases, cannot be changed; records of received signal level (RSL) are distorted by quantization. Other difficulties in estimation of average rainfall per link from signal attenuation include uncertainties due to variability of DSD along the link, wet antenna attenuation and uncertainty in determination of clear air attenuation due to water vapor induced attenuation and scintillation effects.

A first demonstration of the method with commercial microwave links was demonstrated in Israel. Further possibilities include attenuation data at two frequencies, at two orthogonal polarizations, or by measuring their phase difference. The microwave attenuation due to rainfall in tropical regions has not been very widely studied yet. The results of many experiments carried in Amritsar, Pakistan and Malaysia shows that prediction found in these region differ from those predicted by ITU-R equation for the rain rate encountered in the same interval. The research carried out in Amritsar, proved the relation given by ITU-R between attenuation and rainfall rate. In addition to that, a new relation was proposed specially for that particular region which was also shown to be better than the existing ITU-R relation. The research in Pakistan showed that the prediction found in these region differ from those predicted by International Telecommunication Union-Radio equation for the rain rate encountered in the same interval. Thus, the ITU-R model was not found suitable for tropical regions. The research carried out in Malaysia, on the other hand, showed that model proposed by ITU-R was in fact better than the one shown by VIHT. An analysis of these conditions and its results has been done as the first part of the project.[6]

4.2 Need of Now-casting

The forecasting of the weather within the next six hours is often referred to as now-casting. In this time range it is possible to forecast smaller features such as individual showers and thunderstorms with reasonable accuracy, as well as other features too small to be resolved by a computer model. A human given the latest radar, satellite and observational data will be able to make a better analysis of the small scale features present and so will be able to make a more accurate forecast for the following few hours. It is, therefore, a powerful tool in warning the public of hazardous, high-impact weather including tropical cyclones, thunderstorms and tornados which cause flash floods, lightning strikes and destructive winds. In broad terms, now-casting contributes to the :

- Reduction of fatalities and injuries due to weather hazards;
- Reduction of private, public, and industrial, property damage; and to
- Improved efficiency and savings for industry, transportation and agriculture.

In addition to using now-casting for warning the public of hazardous weather, it is also used for aviation weather forecasts in both the terminal and en-route environment, marine safety, water and power management, off-shore oil drilling, construction industry and leisure industry. The strength of now-casting lies in the fact that it provides location-specific forecasts of storm initiation, growth, movement and dissipation, which allows for specific preparation for a certain weather event by people in a specific location.

The software applications in the now-cast environment include algorithms for identifying and tracking thunderstorm movement, identifying boundaries, wind retrieval from radar, as well as a fuzzy-logic engine which allows the user to combine the weighted outputs from the various algorithms to produce a single, combined forecast. Subsequent verification of generated forecasts is available both visually and statistically. In real-time operations the now-cast environment initiates and maintains process control through an auto-restart mechanism. The auto-restarter provides the user with an automated, hands-free forecasting environment. To address issues of disaster management in India, an Indo-US collaborative project for improvement and modernization of the hydro- meteorological forecasting and early warning system in India was formulated (during 2003-2008) as a part of the Government of India (GOI) US Aid for International Development (USAID) Disaster Management Support Project (DMSP). Processing of Indian Doppler Weather Radar (DWR) data for now-casting application under the sub-project Local Severe Storms and Flash Floods was one component of this collaborative project. IMD has recently started upgrading its old analog radar network with a denser network of DWRs. IMD has so far installed five S-Band DWRs manufactured by Gematronik Corporation (Model: Meteor 1500S) at Chennai (2002), Kolkata (2003), Machilipatnam (2004) and Visakhapatnam (2006) replacing the old generation S-Band cyclone detection radars at these stations. IMD has also installed one indigenously built DWR at Sriharikota in 2004.

The state-of-the-art S-band Doppler Weather Radar has recently (June 2010) been installed at Navy Nagar in Mumbai. The Meteorological department traditionally uses satellite pictures and numerical weather prediction models to forecast the rains. With the radar installed, it will be able to forecast the height of the cloud, direction, speed, wind activity inside the cloud. The radar will be able to locate cloud activity of around 250 km from the area. It will also be able to accurately predict the intensity of the rainfall.

Now-casting can also be achieved by predicting rain-rate in near real-time using the microwave attenuation that occurs due to rainfall. The rain-rate thus obtained can be incorporated with a prediction system to generate forecasts.

4.3 Parameters that contribute to floods

Rain falling on the landscape may flow quickly over soil or rock surfaces as runoff to stream channels. Alternately, some water may flow more slowly down-slope toward streams within the soil. Some may percolate downward through pores in soil and fractures in rock to reach the top of the saturated zone (often called the water table). Below the saturated zone, it flows much more slowly as ground-water.Soil characteristics, plants and animals, and slope angle are among the natural factors controlling the proportion of precipitation that is converted to runoff in a given landscape, and the time it takes for runoff to enter a stream. Human changes to these landscape features can greatly influence runoff.

Grassed filter strips in farm fields help reduce runoff and erosion by slowing water velocities in the vegetated areas. Grassy strips also reduce erosion by trapping excess sediment, nutrients, and farm chemicals. Vegetation (including dead vegetative materials) in prairies, forests, and other natural areas plays a similar role.

4.3.1 Infiltration:

The soil surface acts as a filter that lets water pass through (infiltrate) at a rate known as the infiltration rate or infiltration capacity. Runoff may be produced when precipitation or snowmelt adds water to the soil surface faster than it can be absorbed. The excess water remains on the surface and flows down-slope as runoff. For example, if the precipitation rate is 5 centimeters (about 2 inches) per hour, but the infiltration rate is only 2.5 centimeters (about 1 inch) per hour, surface runoff is produced at the rate of 2.5 centimeters (about 1 inch) per hour, even if the soil is not entirely saturated. This mechanism of runoff generation is more common in drier climates where vegetation cover is sparse.

In humid areas with greater vegetation cover, the water table may lie at the surface in low-lying areas or slope hollows, so that the soil there is saturated. Saturated areas expand during rain, as well as during the cold season when plants withdraw little water from the soil. Any rain that falls on these saturated areas must run off over the surface. In times of prolonged heavy rainfall, large areas of a gently sloping landscape may become saturated, and much of the rain that follows runs off rapidly to streams. This was the case during the devastating Mississippi River flood of 1993, when much of the landscape in the Upper Mississippi River Basin appeared as a "lake" on satellite images that detect surface water.

4.3.2 Soil Characteristics:

Infiltration rate is controlled by the nature of the soil, by the plant and animal communities it supports, and by human influences. Where soil is absent and little-fractured bedrock is exposed, water cannot soak in and will run off rapidly. If soil is present, but is very fine-grained and clay-rich, the pore spaces that water must pass through are extremely small; hence, water will infiltrate very slowly compared to sandy soils that readily soak up water. Some finer-grained soils have vertical cracks that form when the soil shrinks as it dries. These cracks allow water to enter more readily, but may close up after the soil is wetted.

Compaction of soils reduces the size of pore spaces and the infiltration rate. Water commonly runs off areas that were compacted through repeated passage of people, large animals, or heavy machinery. Raindrops falling on bare soil also can compact the soil surface in ploughed fields, leading to increased runoff and erosion of farmland. The infiltration rate of a soil depends on factors that are constant, such as the soil texture. It also depends on factors that vary, such as the soil moisture content.

Soil Texture

Coarse textured soils have mainly large particles in between which there are large pores. On the other hand, fine textured soils have mainly small particles in between which there are small pores.In coarse soils, the rain or irrigation water enters and moves more easily into larger pores; it takes less time for the water to infiltrate into the soil. In other words, infiltration rate is higher for coarse textured soils than for fine textured soils.

The Soil Moisture Content

The water infiltrates faster (higher infiltration rate) when the soil is dry, than when it is wet As a consequence, when irrigation water is applied to a field, the water at first infiltrates easily, but as the soil becomes wet, the infiltration rate decreases.

The Soil Structure

Generally speaking, water infiltrates quickly (high infiltration rate) into granular soils but very slowly (low infiltration rate) into massive and compact soils. Because the farmers can influence the soil structure (by means of cultural practices), they can also change the infiltration rate of his soil.

4.3.3 Plants and Animals:

In general, plants and small animals tend to increase the infiltration rate of soils. Some water usually evaporates from plant surfaces before it can fall to the soil surface. A plant cover and litter layer of dead vegetation protects the soil surface from compaction by heavy raindrops, and also slows the delivery of water to the soil surface. Plant stems help slow down water that flows over the soil surface. Plant roots help create openings in the soil, and also draw water from beneath the soil surface and transpire it through leaves back to the atmosphere. Decayed plant matter helps keep fine soil particles (such as clay) from sticking together, thereby increasing infiltration capacity. The burrowing activities of small animals such as insects, worms, and gophers also help keep the soil loose and create small openings through which water can pass.

When the landscape is completely de-vegetated, for example, following a forest fire or during a construction project, a dramatic increase in runoff and soil erosion may result. In desert environments where much of the soil surface lacks vegetation and where bare rock is exposed, most of the rainfall in heavy thunderstorms runs off rapidly and flash floods are common. Yet in dense, humid forests, vegetation and thick, loose soils may absorb water so readily that water rarely runs off the surface.

4.3.4 Slopes

Steep slopes in the headwaters of drainage basins tend to generate more runoff than do lowland areas. Mountain areas tend to receive more precipitation overall because they force air to be lifted and cooled. On gentle slopes, water may temporarily pond and later soak in. But on steep mountainsides, water tends to move downward more rapidly. Soils tend to be thinner on steep slopes, limiting storage of water, and where bedrock is exposed, little infiltration can occur. In some cases, however, accumulations of coarse sediment at the base of steep slopes soak up runoff from the cliffs above, turning it into subsurface flow.

4.3.5 Runoff and Flooding

Water commonly flows down-slope through the loose soil overlying bedrock. This water moves more slowly to streams than does surface runoff. Rain falling on areas where unfractured bedrock is exposed has little opportunity to infiltrate, and instead will run off the surface. A brief thunderstorm in Yellowstone National Park produced considerable surface runoff from these steep cliffs much less likely to cause flooding, but is faster than the creeping flow of groundwater in the bedrock below.

4.3.6 Runoff and Urban Development

Urban development can greatly increase the amount of precipitation that is converted to runoff in a drainage basin. Most paved surfaces and rooftops allow no water to infiltrate, but instead divert water directly to storm channels and drains. Urbanization is of serious concern to water resources for several reasons.

First, the increased amount of water flowing to streams during storms causes larger floods, and floods build to a peak faster because of the rapid flow of water over smooth surfaces.

Second, motor vehicles leave oils and exhaust residues on streets, and household and industrial chemicals also collect on pavement surfaces. These nonpoint-source pollutants are readily washed off during storms, contaminating streams into which urban runoff flows. Careless disposal of hazardous wastes on streets or in storm drains adds to the problem.

Third, most precipitation has no chance to percolate downward to groundwater, so the supply of groundwater to wells is reduced.

Some cities have taken steps to reduce these impacts. Pavement can be constructed so that some water passes through to recharge groundwater, and storm runoff can be routed to artificial basins that allow water to soak in. Along with regulation of hazardous industrial wastes, programs have been developed to educate the public about the dangers of improper disposal of wastes on streets and in storm drains.

Flooding can happen anywhere, whether near to watercourses or not. Floods can even occur during summer months when thunderstorms trigger torrential downpours.

4.3.7 Drainage system

The drainage system sometimes cannot cope with the magnitude of water that collects on surrounding surfaces, especially when they are already saturated with large quantities of water. In this case, even a small amount of additional rainfall can cause flooding.

Flooding can be caused by cracks in broken pipes owned by water companies and heavier than normal rainfall that causes water to run onto roads from fields and over-full rivers. It can also be caused by the collection of mud, leaves and other debris that block drains.

4.3.8 Tides

The chance of big waves meeting ocean-bound runoff has communities taking protective measures. Heavy rains combined with a high tide over six feet can lead to severe coastal floods. The high tides prevent the rain-water from draining into the oceans resulting in heavy floods in the coastal areas. There have been many instances of flooding due to rains when they are accompanied by high tides. These conditions are always a concern in all coastal cities including Mumbai.

Chapter 5

Flood Prediction System

The probability of floods in a particular region depends not only on the amount and duration of rainfall but also on a number of other influential factors. An effective flood prediction system thus should take into account all the above factors for accurate forecast.

Our undertaking though not elaborate has aimed to work on similar lines. It takes into account the rain-rate along with the topography of an area to predict possibility of floods. The basic idea is based on the fact is that in case of rainfall the low-lying regions are more likely to get flooded, the water then eventually moving to the other areas. This can give a fair idea of the time in which the any region under consideration is likely to flood. This concept has been implemented by dividing the area into watersheds. A watershed is a basin-like landform defined by highpoints and ridgelines that descend into lower elevations and stream valleys.

5.1 Defining the topography:

The topography of an area is defined in terms of latitude, longitude and height above the sea level of various points in the area under consideration. The number of points recorded depends on the desired accuracy of representation of topography. The greater the number of points more accurate is the reconstruction of an area.

For the sake of demonstration and verification the region from Vile Parle (West) to Jogeshwari (West) in Mumbai. A total of 1500 locations were recorded taking into consideration the three defining parameters. Depending on the availability and accuracy of data around 1004 points were considered for the final observation. The data required was collected from that available on Google maps. The amount of data required is not precisely available with the BMC and can be most accurately recorded from the services provided by Google maps.

5.2 Creating a grid of recorded data:

A point with lowest value of latitude and longitude is taken as the origin also termed as the reference point. The relative positions of all other recorded points with respect to the reference are calculated. This relative positioning is of utmost importance in recreating the topography with exact locations and dimensions for the new grid.

The dimensions of the grid are then fixed depending on the desired resolution and the need of representation. The area is then divided into intervals along length and width to form a suitable grid. All the points lying with a given cell of the grid are noted. The average heights of all the points is calculated and assigned to the cell. This cell represents the area enclosed by the intervals along length and the breadth. The initial total number of points is thus grouped according to their location and their average heights determined. This process is termed as Grid Averaging.

5.3 Finding the number of sinks:

Sinks are the lowest points of a region where the water from all the neighboring areas is likely to flow. The sinks can be identified by determining the direction in which the water from a given region is likely to flow. Water from any given region will move to its neighbor which has the lowest altitude. Thus the region where the water is most likely to accumulate is the sink.

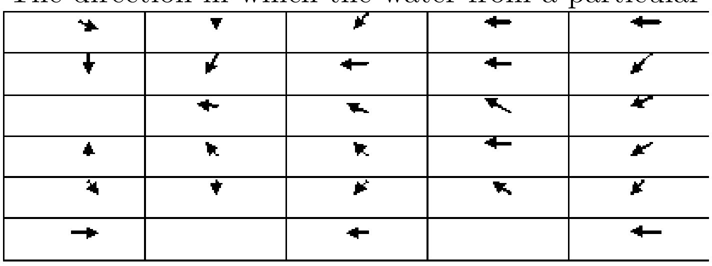
Consider an area as shown in the figure The numbers in the cells denote the averaged height of that particular area. The size of the matrix has been set as below for the purpose of simplicity.

Figure 5.1: Watershed Topography categorized according to their averaged heights

9.1	7.7	7.9	12.27	13.16
7.45	6.63	9.81	19.95	20.83
6.0	7.5	10.1	13.45	17.7
8.8	8	10.095	13.44	15.5
7.9	9.5	12.9	12.2	16.8
6.9	5.2	17.3	11.1	16.51

For the topography as above, the water arriving at the first cell (height 9.1) will flow into the cell with height 6.63.This is because of all its neighbors this cell has the lowest altitude and greater chance of retaining water.

Figure 5.2: The direction in which the water from a particular cell will flow



The arrows indicate the direction of flow. For example the water from the first cell of height 9.1 will flow into the cell having the height 6.63 since this is the lowest value among its neighbours and hence the direction of the arrow. Similarly, the arrows to the other cells have been assigned. The blank cells indicate that the corresponding regions only receive water from their neighboring areas and itself cannot contribute to water accumulation in any other region. These areas are the sink regions. These directions also play a role in determining the watersheds in an area. A sink and the regions contributing to water accumulation in that sink together form a watershed.

5.4 Finding the watershed

Initially every regions is denoted by '1'.For every cell that contributes to accumulation in a particular regions the count for that particular region is incremented by '1'.Thus the total number of regions contributing to accumulation in a given area (cell) can be calculated. Accordingly the above representation is transformed into the following figure.

Figure 5.3: Watershed table

1	1	2	2	1
1	6	3	1	1
6	2	1	2	1
1	1	3	2	1
1	1	1	2	1
1	6	1	3	1

Sinks however are not just the lowest regions; they are those regions which only receive water and do not contribute to flooding in other areas. Thus for the given topography the sinks occur at points with altitude 6, 5.2 and 11.1.All heights being taken in meters. The direction of flow thus plays a crucial role in identifying a watershed, since a region maybe at the lowest elevation but it may not be a sink.

Once a particular region is filled with water it will overflow to the neighbor having the lowest height. Extending this concept to the watersheds, water will flow from one watershed to the next over the smallest height. This height is known as the spill height. The watersheds are thus assumed to be connected to each other by their spill-heights. As shown in the figure below.

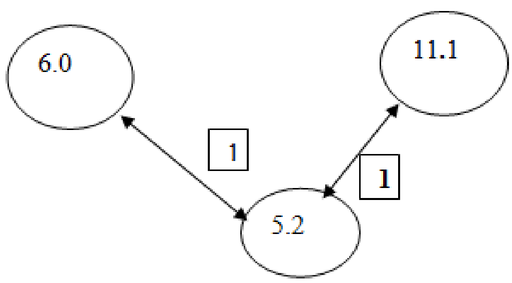


Figure 5.4: Watershed connected by their spill heights

The circles denote the watersheds with their sink values specified. The links give the values the lowest height common to the watershed over which the water will move to the next watershed. The bidirectional nature of the links indicates that water may flow from either region to the other depending on the extent of accumulation in those regions.

5.5 Flooding

The process of flooding of each area can be defined by taking into consideration the volume of a cell and its fill rate.

Volume of any cell is given by Area of a cell X Height up to which the water will fill before flowing over.

Fill Rate is defined as the time taken for a particular area to fill. It is given as

Rain-rate *No of cells

Therefore,

Spill Time = Volume/Fill Rate

When an area under consideration experiences rainfall the rain water as well as the water from the neighboring areas flows into the sinks. The sinks once underwater the additional water overflows into the neighboring areas.

Once a watershed is completely inundated water from that region will move into the neighboring watershed over the smallest height. Thus the two watersheds merge effectively though not physically. Thus the effective volume and spill time changes for the new apparent topography. Therefore every time watersheds merge the topography changes apparently and hence the spill time and spill volume until finally the region is submerged.

Thus if the rain-rate is known the amount of time in which a region will be flooded can be determined. Also similarly the extent to which a given area will be flooded in a particular time for a particular rain-rate can be determined. Thus floods can be predicted.

Along with the basic topography, a number of parameters contribute to flooding. An integration of these parameters is important for well defined accurate predictions. However due to insufficient data the other parameters have not been included.[2][3]

Chapter 6

Experimentation and Result Analysis

This chapter gives step by step results and their explanation in the course of running the simulation. Initially the heights of different regions in the selected topography were recorded and stored. Then grid averaging has been performed, so as to organize the areas into groups and then performing averaging operation, average height of the sub-division is found, after the entire area is sub-divided the corresponding values are stored in different cells. After this process has been done, firstly the map of the region under consideration is plotted based on the height of each cell.

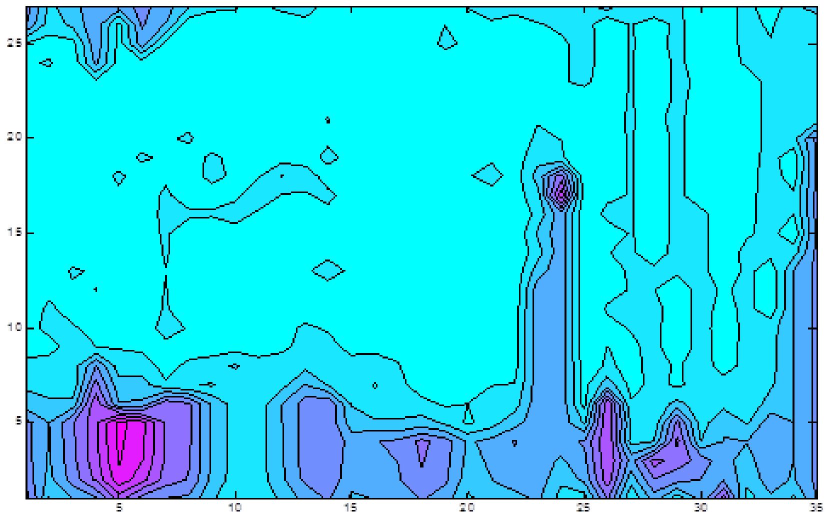


Figure 6.1: Elevation Grid

This is a 2D representation of the area under consideration .The extent of the region is determined on the basis of the latitude and longitude of the various points in the region. The variation of the shades of blue indicates the variation in height of the points within the region. The deeper pink indicates the lowest points in the area whereas the lightest blue denotes the highest points.

Further, based on the heights of cells, the sinks present in the region under consideration are found out. Sink is said to be the cell where water gets accumulated. The cells contributing to a particular sink together form a watershed.

The model displays the topography of the region under consideration. In addition it also gives the time required for a particular region to get flooded. The flowing are the simulation results of the model.

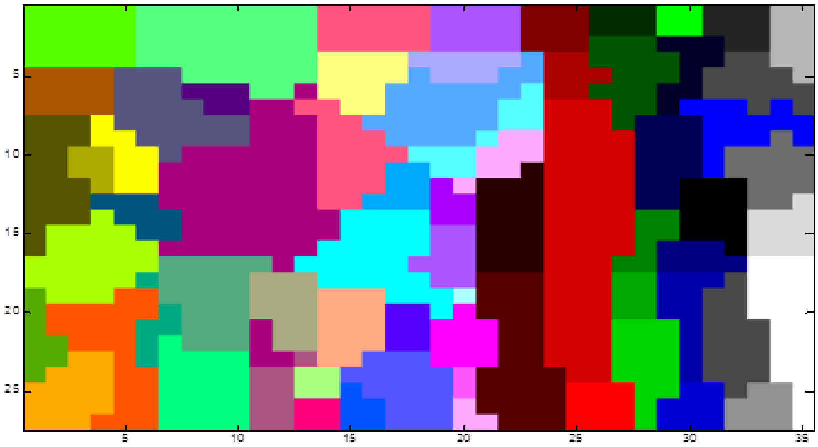


Figure 6.2: Watershed Map

This is known as a watershed map. Each different color denotes a different watershed (a sink and all areas contributing to that sink) .The watersheds border on a number of different watersheds to form the complete area under consideration. A single color represents the mean height of that particular watershed above the sea-level.

Each node represents a sink within a watershed. The number of nodes therefore is equal to the number of sinks i.e number of watersheds. The watersheds (nodes) are shown to be connected to the bordering watersheds with links .The lowest height on the boundary is specified on the link i.e it denotes the path through which water from a particular watershed will spill out on overflowing. All links are bi-directional to indicate that the water may overflow from any region that fills in earlier in time to its neighbor.

This is the 3D representation of the area under consideration. The X-Y plane defines the geographical extent of the area .The Z axis gives the height of the individual regions above the sea-level. The shown region is mapped based on the latitude and longitude of the points within the region and their relative positions from each other.

The following is the a succession of images of the simulation displaying the flooding of a particular region.The region considered here is the watershed number 40 .The unit rainfall and the time of rain are also specified. This is the 3D representation of the area under consideration. The X-Y plane defines the geographical extent of the area .The Z axis gives the height of the individual regions above the sea-level. The shown region is mapped based

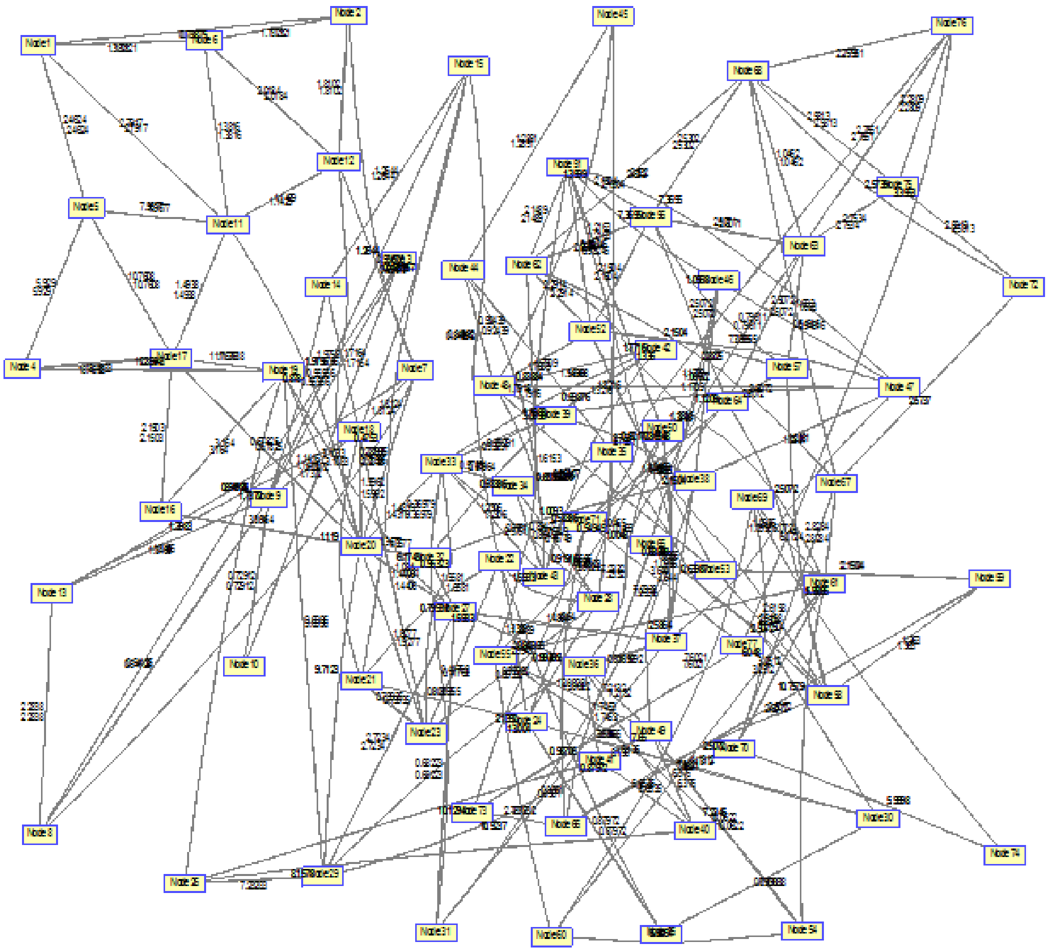


Figure 6.3: Watershed Graph

on the latitude and longitude of the points within the region and their relative positions from each other.

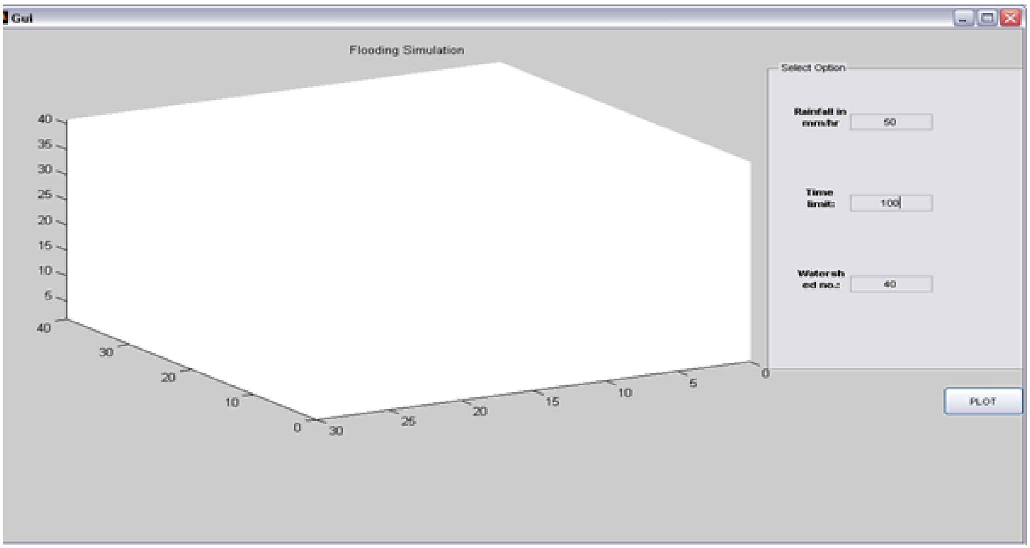


Figure 6.4: The plot shows the region prior to the beginning of the simulation.

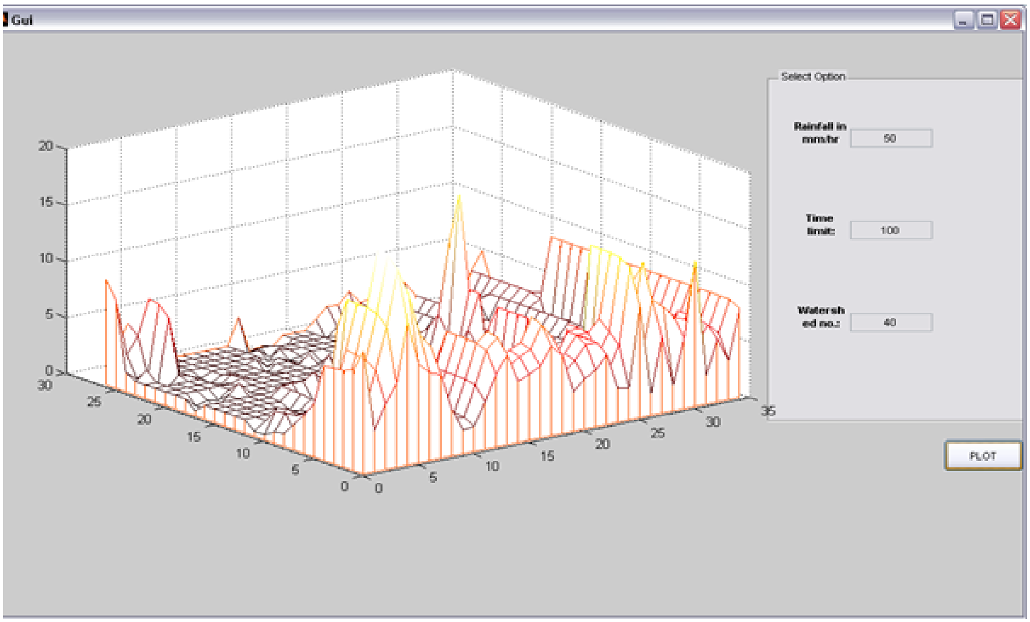


Figure 6.5: The plot shows the region after the simulation began.

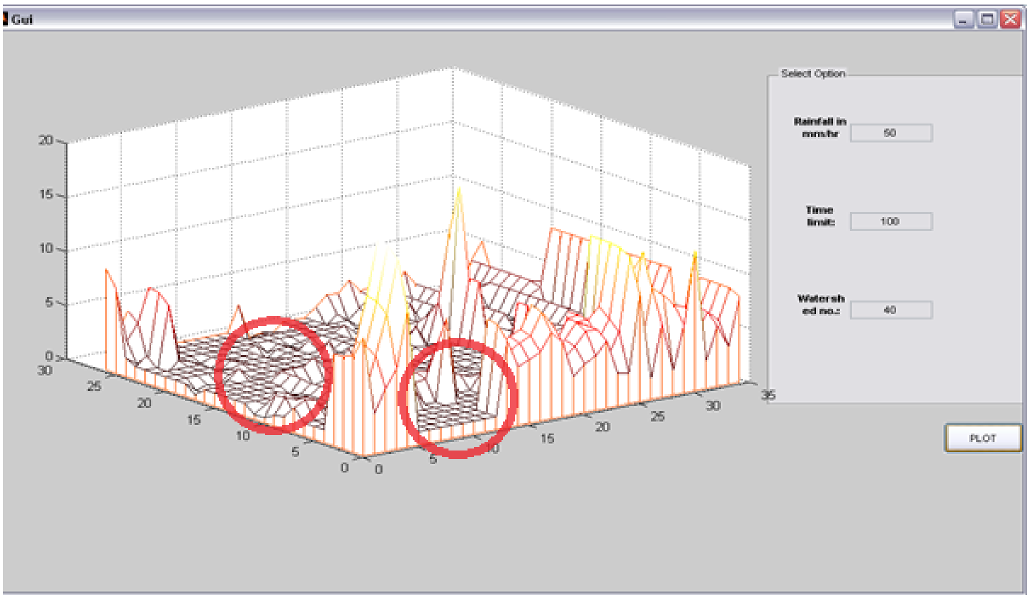


Figure 6.6: The plot shows the area getting flooded (marked in red)

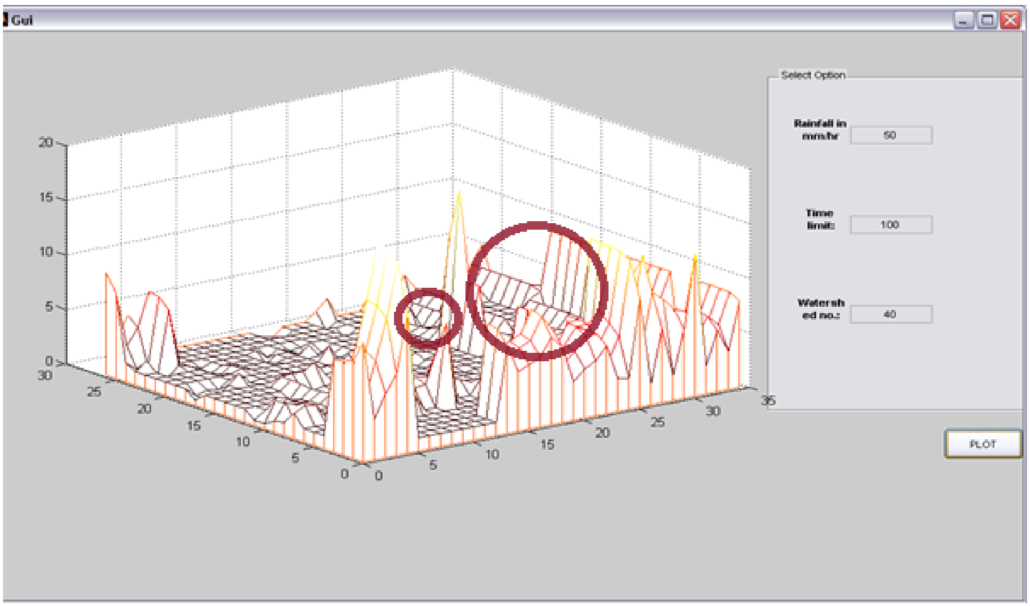


Figure 6.7: The plot shows different regions getting flooded (marked in red)

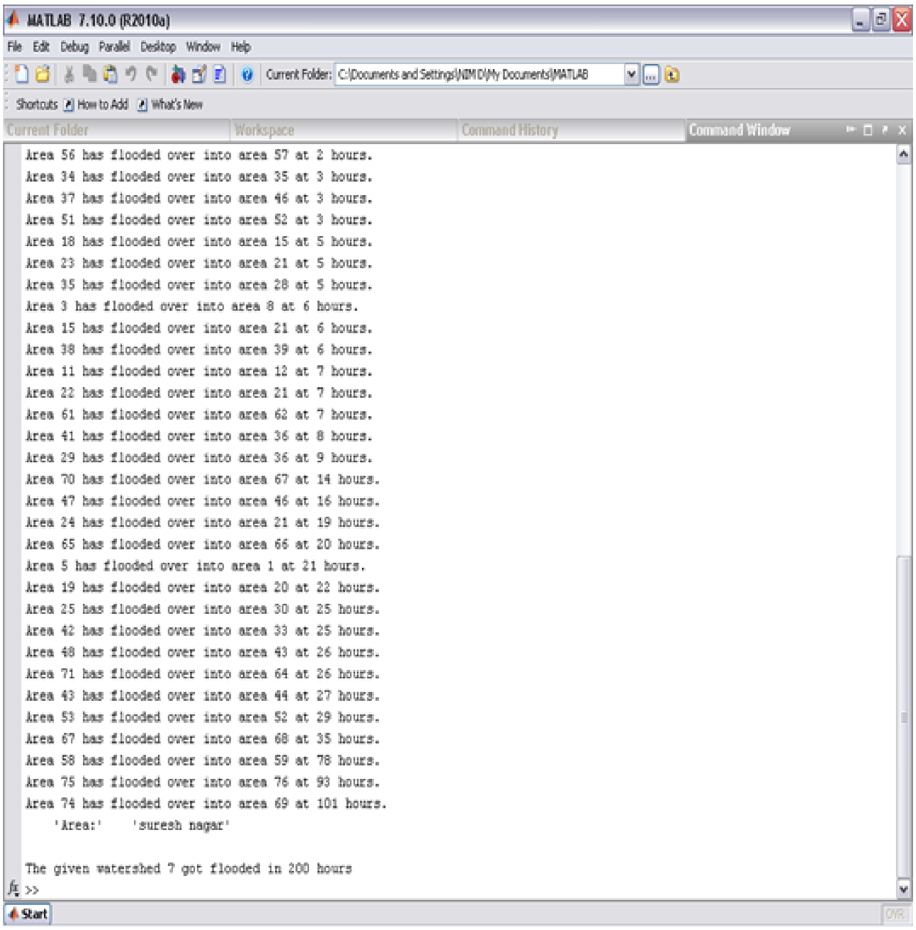


Figure 6.8: This plot gives the time duration in which the individual regions (watersheds) flooded over. Also the time required for the region on interest to flood is displayed along with the name of the area which that watershed represents.

Chapter 7

Comparison of Rain Attenuation Models

This section gives the comparison between various rain attenuation models with the ITU-R model,which give a relationship between rain rate and microwave attenuation due to rain.

The models generally fall into two categories: (a) those that attempt to define the physics of the process and (b) those that use empirical approaches with simplified assumptions. Due to the lack of world-wide information on many of the physical inputs needed to provide accurate results using the models of type (a), type (b) models - empirical procedures - have tended to be used most often and with usually the best results.

It has been reported that most of the available rain attenuation prediction models provide an annual average accuracy of the order of 30%.The model accuracy reported is supported by recent testing efforts in the ITU-R. A lower limit to the prediction accuracy for rain attenuation models is set by the natural variability of the rain process itself, which is thought to be around 20% on an annual basis. Results indicate that the rain attenuation element of the model provides the best average accuracy globally between 10 and 30 GHz and that the combined procedure gives prediction accuracies comparable to uncertainties associated with the year-to-year variability of path attenuation.

7.1 ITU-R Model

The Crane and other models were believed to overestimate the attenuation compared to the CCIR model. Yamada used 124 data sites and proposed changes to the CCIR model that are represented in the present ITU model. After improvement to the CCIR method, errors in the mean attenuation were less than 20% at availabilities of 99.9% or better.

For prediction of rain fade attenuation using the ITU 530 standard, rain rate at the 0.01% exceeded level for the zone of interest is required, frequency, path length, frequency, and attenuation factors from ITU-R 838 . The ITU model consists of simple equations and is known for ease of use.[9]

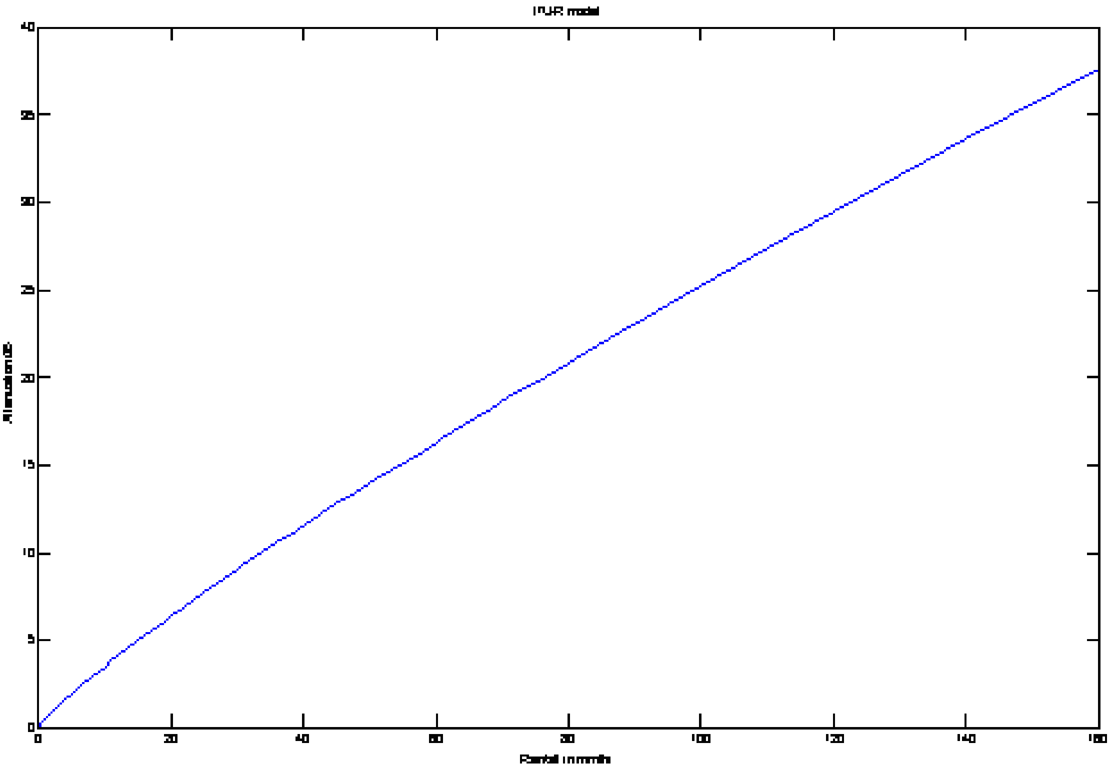


Figure 7.1: The ITU-R model

7.2 The Indian Model

The proposed rain attenuation prediction model is somewhat similar to the one recommended by the ITU-R where the rain related input to the model is the rain intensity at the 0.01% probability level. The method was derived on the basis of the log-normal distribution using similarity principles. Both point rain intensity and path attenuation distributions generally conform to the log-normal distribution. In homogeneity in rain in the horizontal and vertical directions are accounted for in the prediction. The same procedure applies for both slant paths and terrestrial paths. The method is applicable across the frequency range 4 to 35 GHz and percentage probability range 0.001% to 10%.

Rain zone models such as the ITU-R and Crane global model embody broader climatic features of widely separated regions. As such, they tend to be rather coarse and may not

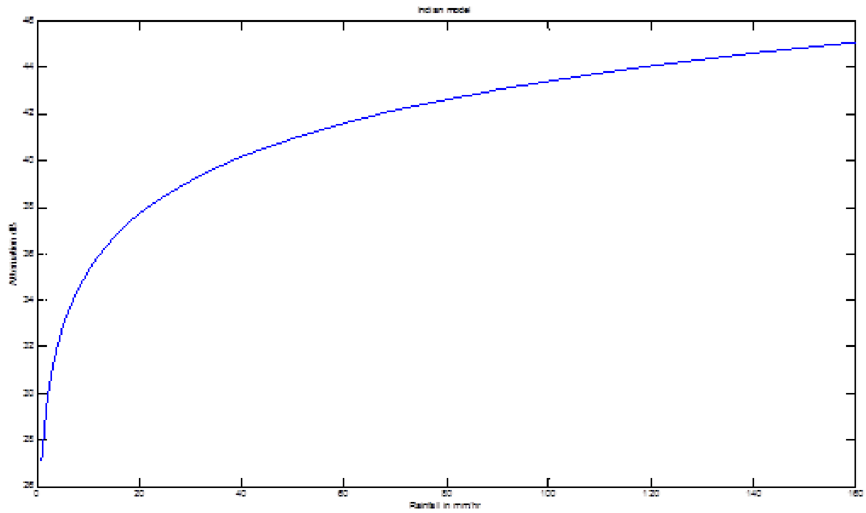


Figure 7.2: The Indian rain attenuation prediction model

always be appropriate for obtaining site specific rain intensity data. Conversion of long integration time rain intensity to short integration time rain rates is more direct and can be made site specific using widely available rainfall data from meteorological stations. The method can be used to predict individual impairments as well as their combined effects at frequencies between 4 GHz and 35 GHz although the best accuracy will be found between 10 and 30 GHz. The method appears to be able to predict total path attenuation with an overall error of less than 20%. The method predicts the long-term average attenuation values for a given link and provides predictions across the probability range of 0.001% to 50%. This range is thought to be adequate for most telecommunication system design purposes. Use of the model outside the specified range is not recommended since all factors required for a complete description of the cumulative distribution are not included.[10]

7.3 Simple Attenuation Model

The Simplified Attenuation Model (SAM/CCIR) was developed for NASA to provide a simplified technique for hand calculation. This model [Pra86] is based on nominal water droplet sizes and distribution and allows calculation of attenuation rate (dB/km) due to a specified rainfall rate. The attenuation rate can be approximately expressed by Equation 5.9, where R represents the rainfall rate in millimeters per hour and parameters 'a' and 'b' are approximated.

$$k_{rain} = aR^b \tag{7.1}$$

$$a = 4.21 * 10^{-5} * f * 2.42 for (2.9GHz <= f <= 54GHz) \tag{7.2}$$

$$a = 4.02 * 10^{-2} * f * 0.669 for (54GHz <= f <= 180GHz) \tag{7.3}$$

$$b = 1.41 * f - 0.0779 for (8GHz <= f <= 25GHz) \tag{7.4}$$

$$b = 2.76 * f - 0.272 for (25GHz <= f <= 164GHz) \tag{7.5}$$

The ITU-R model is a combination of several techniques based on many site-years of propagation data and gives good results globally of rain attenuation exceeded on earth-space links at annual and worst month time percentages in the range 0.001-1 % and 0.007-2.94%. However, to assess the impact of rain on low-availability systems, rain attenuation exceeded at annual time percentages to 1% must be determined. This is done using the SAM (Simple Attenuation Model) model, which determines rain attenuation as a function of the equi-probable rainfall rate, and has been found to give better agreement with measurements than the ITU-R model at high time percentages equal to 0.1%.

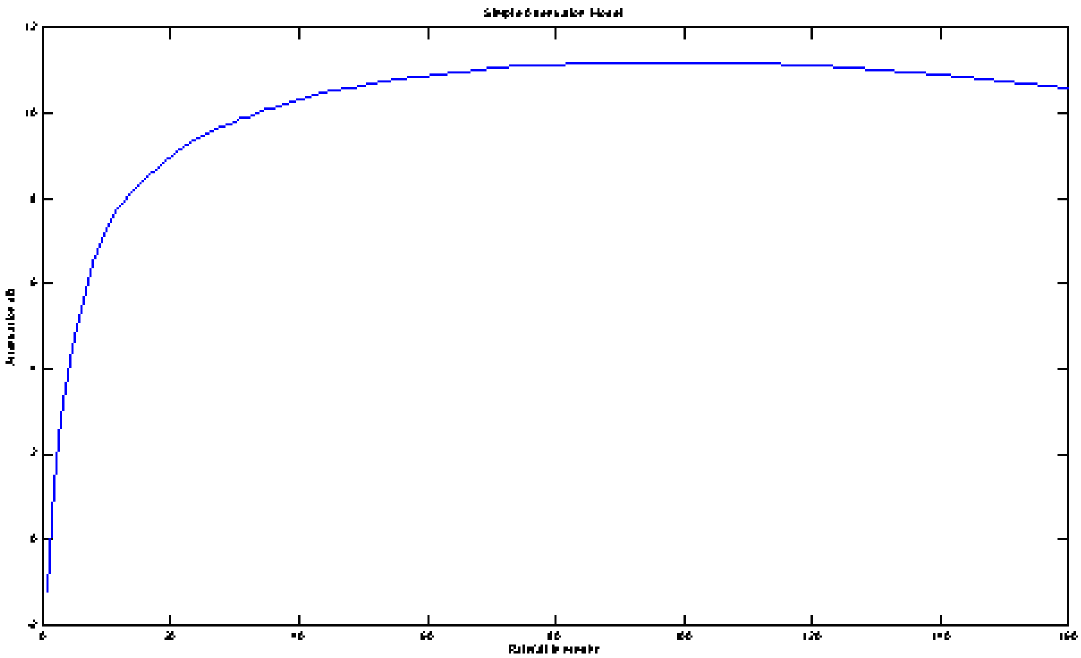


Figure 7.3: The Simple attenuation model

The attenuation increases with an in increase in rainfall. However the characteristics also exhibit a fall in attenuation at higher values of rainfall which does not satisfy the general rule and hence questions the credibility of the model.[11]

7.4 Crane Model

The "Crane" models, after Robert K. Crane, are popular for satellite-earth links but also have terrestrial models.

In the equations below ,AR is the rain attenuation in dB, R is the point rain-rate in mm/hr, and d is the distance in km. Constants 'a' and 'b' are rain attenuation coefficients that are functions of frequency and polarization and are tabulated.

$$A = aR^b * (e^{ubd} - 1)/ubfor0 <= d <= D_0 \tag{7.6}$$

$$A = aR^b * ((e^{ubD_0} - 1)/ub - (B^b e^{cbD_0})/cb + (B^b e^{cbd})/cb) \tag{7.7}$$

$$D_0 3.8 - 0.6ln(R) \tag{7.8}$$

$$B = 2.3R^(- 0.17) \tag{7.9}$$

$$u = ln(B * e^(c * D_0))/D_0 \tag{7.10}$$

$$c = 0.026 + 0.03ln(R) \tag{7.11}$$

For paths longer than 22.5 km, the attenuation AR is calculated for a 22.5 km path, and the resulting rain attenuation is multiplied by a factor of (d /22.5). The Crane rainfall zones are defined differently than the ITU zones with more defined zones in the US than the ITU zones. The Crane models predict a larger attenuation than the ITU model. Calculation by the ITU model is straightforward by scaling the 0.01% rain rate and by using an effective path length reduction factor to account for the cellular nature of heavy rainfall. Mean cumulative distributions of rainfall zones are defined geographically in ITU-R 837.

The Crane Global model requires solution of about 8 equations to obtain the path-averaged rain rate and a piecewise representation of the path profile by exponential functions. The initial two-component Crane model first computes the volume cell contribution from the path integrated rain rate produced by a volume cell and the debris contribution based on the length scale for the debris path. About 10 equations are involved.

For the revised two-component Crane model, spatial correlation functions are included and an integral equation for the debris path. It also includes a prediction for satellite path diversity.

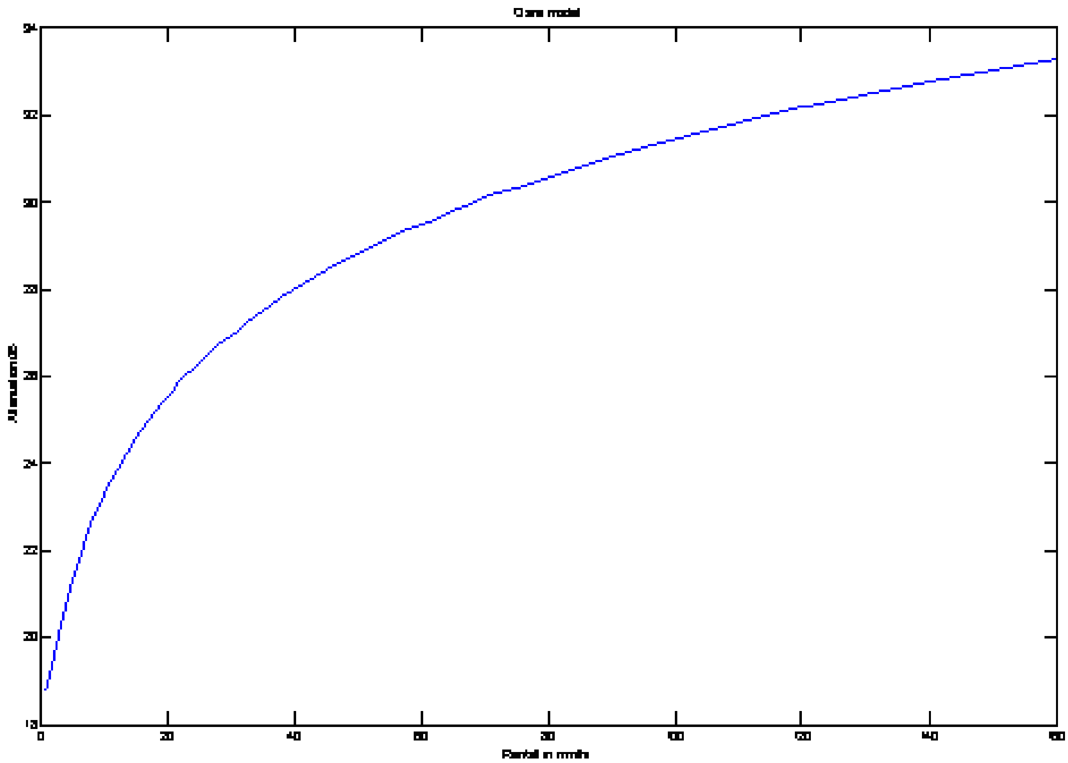


Figure 7.4: The Crane model

7.5 Earth to Space Model

Rain attenuation modeling on satellite paths has been done by many researchers over the last three decades. With the introduction of Ku-band satellite communication services in the tropical and equatorial region, prediction of rain attenuation has become an important factor. Several empirical and non-empirical rain attenuation prediction models that have been developed are based on the measurement data obtained from temperate regions. Most of these existing rain attenuation prediction models do not appear to perform well in high rainfall regions.

The ITU-R model is currently being widely used by many researchers. Cumulative distribution empirical evidence shows that the ITU-R model underestimates the measured rain attenuation cumulative distribution when applied to tropical regions, leading to a poor prediction. Therefore a modified ITU-R model was developed using the complete rainfall rate cumulative distribution and the horizontal path length to calculate the cumulative distribution of rain attenuation for tropical and equatorial regions.

The modified ITU-R model retains the concept of an equivalent rain cell. The horizontal projection of the slant path, LG was modified based on the rain height, elevation angle, reduction factor, and the rainfall rate at the measurement sites. Therefore this model was revised, so that it can be used at tropical countries with the antenna elevation angle varying from 400 to700. In the ITU-R model, the rainfall rate exceeded at 0.01% of time is used for predicting the correspondent value of rain attenuation. The extrapolation formula was also used to calculate the rain attenuation exceeded at other percentages of time between 1% and 0.001%. In the proposed model, the extrapolation formula was modified based on the rain attenuation data obtained from the measurement sites. The rain attenuation exceeded during P% of time is then given by:

$$A_p = A_{0.01} * 0.12 * p^-(0.58569 + 0.06104 log(P)) dB \tag{7.12}$$

Where, $A_{0.01}$is the rain attenuation exceeded at 0.01% of time. The specific attenuation is a function of the rainfall rate, $R_{0.01}$ exceeded at 0.01% of time is given by:

$$\gamma = k(R_{0.01})^{\alpha} dB/km \tag{7.13}$$

Where, k and α are frequency and polarization parameters. The horizontal reduction factor, $r_{0.01}$ exceeded at 0.01% of time is given by:

$$r_{0.01} = (1 + L_G/Lo)^-1 \tag{7.14}$$

where, L_o is equivalent rain cell length and L_G is horizontal projection of the slant path calculate by using the rain attenuation data at the measurement site. This parameter is given by:

$$L_G = (3167.9714 + 2088.3369(L_S \cos(\theta)) - 66.345562(L_S \cos(\theta))^2 - 2182.7255(ln(L_S \cos(\theta)))^2 + 1229.52 \tag{7.15}$$

Where, $L_S$is the slant path length and θ is the antenna elevation angle.
The rainfall attenuation, $A_{0.01}$ exceeded at 0.01% of time is given by:

$$A_{0.01} = \gamma * r_{0.01} * L_S \tag{7.16}$$

The mean error, μ_e and standard deviation, σ_e are used to calculate the Root Mean Square, D_e(RMS).
The parameter is defined as follows:

$$D_e = (\mu_e^2 + \sigma_e^2)^0.5 \tag{7.17}$$

According to evaluation procedures adopted by the CCIR the preferred prediction method is the one producing the smallest RMS values.

On comparison it is seen that the proposed rain attenuation model for earth-to-space performed better than the ITU-R model. The model can be used for different elevation angles and it is simply to use.

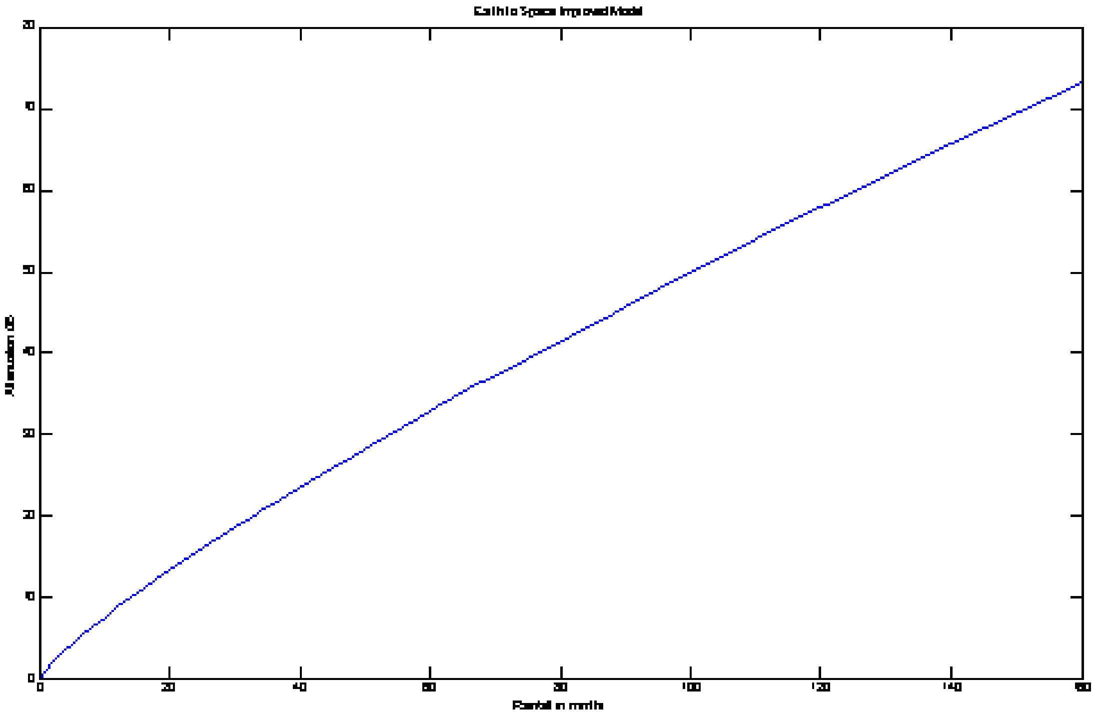


Figure 7.5: The Earth to Space Improved Model

According to evaluation procedures adopted by the CCIR the preferred prediction method is the one producing the smallest RMS values.

On comparison it is seen that the proposed rain attenuation model for earth-to-space performed better than the ITU-R model. The model can be used for different elevation angles and it is simply to use.

7.6 Tropical Model

Rain attenuation is a major limiting factor above 10 GHz frequency bands to be used in radio communications. It is also a relevant issue for space-borne radars for cloud and precipitation characterization. Although, other forms of hydrometeors (snow, hail etc) also affect the performance of the system, the attenuation due to rain is most severe. Rain attenuation modeling is usually done in terms of drop size distribution (DSD). But, the variability of DSD for different climatic regions is a major concern, especially for the tropical region, which has a huge diversity in climatic conditions. A few attempts have been made to characterize the rain attenuation over this region. In the absence of measured attenuation data, DSD measurements can provide useful information on the variation of the rain attenuation.

Rain drop size distributions (DSD) were measured with disdrometers at five different climatic locations in the Indian tropical region. The distribution of drop size is assumed to be lognormal to model the rain attenuation in the frequency range of 10-100 GHz. The rain attenuation is estimated assuming single scattering of spherical rain drops. A comparison shows that significant differences between ITU-R model and DSD derived values occur at high frequency and at high rain rates for different regions. At frequencies below 30 GHz, the ITU-R model matches well with the DSD generated values up to 30mm/h rain rate but differ above that.

To estimate the direct relationship between rain fall rate and the rain attenuation, normally, a power-law relationship of the following form is considered according to ITU-R standard.

$$A = k(R^{\alpha}) \tag{7.18}$$

Where k and α are constants.

From the regression analysis of the modeled attenuation with the rain rate, the constants are again determined for different locations and different frequencies in the tropical region as shown. In the table below SHL stands for Shillong, AHM stands for Ahmedabad, TVM stands for Tiruvananthapuram, KGP stands for Kharagpur and HAS stands for Hasan.

The DSD modeling in terms of lognormal function has been carried out to estimate the rain attenuation at different places in Indian region in the frequency range of 10-100 GHz. Results show that there is a strong variability of specific rain attenuation at different locations at higher rain rates. DSD is found to depend strongly upon local climate of the different locations in the Indian region. It also comes out from the analysis that the ITU-R model overestimates rain attenuation at frequencies above 30 GHz at all rain rates over the Indian region. At smaller rain rates and in the frequency range 10-30 GHz, the ITU-R model performs well. It is found that for higher rain rates, specific attenuation values vary significantly at different locations and also differ from the ITU-R model. The results will be helpful in understanding rain attenuation variation and designing communication systems at EHF bands in the Indian regions.

Figure 7.6: k and a for different regions are given at different frequencies

	SHL		*AHM*		*TVM*	
f (GHz)	k	α	k	α	k	α
10	0.01115	1.199	0.0081	1.249	0.0057	1.316
20	0.1329	0.9289	0.1204	0.9557	0.1106	0.9723
30	0.3385	0.8492	0.2932	0.8922	0.2625	0.9169
40	0.7221	0.7414	0.6262	0.7934	0.569	0.8182
50	1.093	0.6717	0.9788	0.7224	0.9404	0.7361
60	1.319	0.6366	1.214	0.6838	1.227	0.6865
70	1.423	0.6209	1.329	0.666	1.385	0.6615
80	1.464	0.6141	1.373	0.6586	1.453	0.6506
90	1.477	0.611	1.386	0.6555	1.476	0.6462
100	1.476	0.6095	1.386	0.654	1.479	0.6442
	KGP		*HAS*		ITU-R	
f (GHz)	k	α	k	α	k	α
10	0.0116	1.193	0.0060	1.289	0.0117	1.2371
20	0.1304	0.9328	0.1082	0.9686	0.0938	1.0198
30	0.3241	0.8577	0.2691	0.9036	0.2347	0.9311
40	0.6719	0.7557	0.5778	0.8099	0.4352	0.8549
50	1.003	0.6888	0.9622	0.7313	0.6536	0.7978
60	1.203	0.6548	1.29	0.6799	0.8560	0.7571
70	1.296	0.6394	1.502	0.6508	1.0284	0.7280
80	1.332	0.6329	1.614	0.6361	1.1686	0.7068
90	1.342	0.6299	1.661	0.6292	1.2801	0.6910
100	1.341	0.6285	1.676	0.6259	1.3675	0.6789

Firstly, the proposed system requires the measurement of rainfall of a given region. The traditional method to measure rainfall has been with the help of rain gauges. The gauges are of two types viz., non-recording and automatic recording gauges. The non-recording gauges are used less and automatic recording ones are preferred. The automatic recording gauges record the cumulative amount of water with time continuously on graph paper. Thus the accuracy of automatic rain gauges is more as it gives more number of readings. In addition to this method satellite imagery is also used but it is not sufficiently efficient for fast prediction.

It is also possible to extract rainfall data from the amount of corresponding microwave attenuation. In other words, the amount of rainfall of a given region can be found out by using the information regarding the extent of degradation of microwave signals. There are a number of relations that are used to give more accurate results than the other. The factor to be taken into account, is, which one of these models gives most accurate results for the region under consideration. Thus it can be seen that the ITU-R relation has definite flaws when it comes to implementation in tropical regions. This can be traced to high amounts of rainfall in tropical regions and corresponding drop sizes. Further, depending upon the region under observation, appropriate relation can be chosen so as to measure the rainfall rate through the use of microwave attenuation data. The advantage of using microwave attenuation data for calculation of rain-rate is the prospect of monitoring the system on a real-time basis. This brings to light the concept of now-casting which enables the authorities to keep an eye on natural disasters like rain-flood and take necessary action before the situation worsens.

Secondly, the proposed system involves the calculation of time in which a particular region might get flooded when provided with the intensity of rainfall in mm/hr. This time that is predicted is known as spill time. Most of the current systems have low sensitivity, that is, they are slower to respond to extreme flood causing events like rain flood. The reasons behind it are the lack of continuous monitoring of rainfall rate and an absence of any fixed algorithm for prediction of flooding time. There exists an algorithm which has been usually used to predict river floods in a particular area. The proposed system, thus, involves integration of this algorithm to predict rain-floods, that is, to predict the time required for a given area to get flooded. This algorithm takes rainfall rate at a given instant of time along with the heights of sectors within the area under consideration as input and gives the spill time of that area. The data regarding heights of different regions within the area needs to be recorded. The rainfall data required can be obtained from the earlier method, that is, from microwave attenuation. The advantage of this system is that since the rainfall rate can be continuously monitored through measurement of microwave attenuation, corresponding spill time can be calculated at the same rate. The topographic data that is the data regarding heights of regions within the areas can be stored beforehand. As the rain rate gets fed as input to the system in real time, the spill time of any desired region within the area under consideration can be calculated equally efficiently. Thus, in case of extreme events the response time of the system would be much less. As a result, the process of issuing of warnings can be sped up so as to prevent the loss of human life as well as proper.

Chapter 8

Conclusion and Future Work

8.1 Conclusion

The relation proposed by the ITU-R does not provide accurate results for the tropical regions. It can be modified to according to the conditions in the tropical region. The main reason for the variation in attenuation due to rainfall in the tropical regions is the higher amount of rainfall and different drop size distribution. Although efforts have been made to develop a relation suitable for the tropical regions no particular relation has yet been developed.

The method of flood prediction proposed in this project gives satisfactory results for the area considered. The time required for the particular area to get flooded for a particular rate of rain can be determined successfully. However due to limited number of input parameters considered the large scale application of the project is restricted.

8.2 Future Work

The need of the hour is a system that provided faster flood prediction in cities. It can only be achieved a means of faster rain-rate measurements accompanied by the knowledge of topographical and structural characteristics of a region to achieve more accurate prediction.

Therefore, efforts to determine an improved relation between the rain-rate and corresponding attenuation in the tropical region are crucial for accurate rain-rate measurements. In addition elaborate details about the structure and topography of an area are important .This would require the assimilation of all factors contributing to floods. A model incorporating the drainage system, soil and the plan of a city in addition to basic topography is required for accurate results.

Thus a complete system comprising of all the necessary parameters should be the goal for the future. Also the prediction results can be relayed to the concerned individuals with means of broadcast system taking input from the prediction model. The system could be a simple GSM modem. A wise combination of all the above can thus provide a absolute system for flood prediction in flood prone cities like Mumbai.

Bibliography

8.3 Reference Papers

[1] Christian Mtzler, Ernest Koffi and Alexis Berne (2009) -'Monitoring Rain Rate with Data from Networks of Microwave Transmission Links', EUCAP, Berlin.

[2] Z. X. Zhou, L. W. Li, T. S. Yeo, and M. S. Leong(June 2000)-'Cumulative distributions of rainfall rate and microwave attenuation in Singapore's tropical region', Radio Science ,Vol.35 ,No 3.

[3] Ashok Kumar, I. S. Hudiara, Sarita Sharma and Vibhu Sharma (2009) - 'Rain Attenuation Measurements in Amritsar over terrestrial microwave link at 19.4 & 28.75 GHz', Guru Nanak Dev University.

[4] F. S. Marzano, D. Cimini, and R. Ware (July 2005) - 'Monitoring of rainfall by ground-based passive microwave systems: models, measurements and applications.' Advances in Geosciences.

[5] S. Das, A. Maitra, A. K. Shukla (2010)-'Rain Attenuation Modeling In 10-100GHz Frequency Using Drop Size Distributions For Different Climatic Zones In Tropical India', Progress in Electromagnetic Research B, Vol. 25.

[6] M. R. Islam,Tharek Rahman, Sheroz Khan, Khalifa O., and M. M. Rashid(2004)-'The Rain Attenuation Prediction Methods From 10-TO 37-GHZ Microwave Signals Based On Data Measured In Malaysia',International Conference on Electrical and Computer Engineering.

[7] Mandeep Singh Jit Singh, Syed Idris Syed Hassan and Mohd Fadzil Ain(2007)-'Rainfall Attenuation and Rainfall Rate Measurements in Malaysia Comparison with Prediction Models',American Journal of Applied Sciences 4(1).

[8] A. K. Bhatnagar, P. Rajesh Rao, S. Kalyanasundaram, S. B. Thampi, R. Suresh and J. P. Gupta(2003)-'Doppler radar - A detecting tool and measuring instrument in meteorology',Current Science, Vol. 85, No. 3.

[9] Damodar Magdum, Ajitsinh Jadhav-'KA-Band Rain Attenuation Over Major Indian Cities',Dr.D.Y.Patil College of Engineering and Technology..

[10] Asoka Dissanayake, Jeremy Allnutt, Fatim Haidara-'A Prediction Model that Combines Rain Attenuation and Other Propagation Impairments Along Earth-Satellite Paths',Online Journal of Space Communication.

[11] I.E. Otung(1996)-'Comparative Evaluation Of Rain And Scintillation Fading On Low Availability KA-EHF Bands VSAT Satellite Systems',0-7803-3019-6/96/3.00 1996 IEEE.

[12] Sanjaya Gurung,Jingshu Zhao-'Attenuation Of Microwave Signal And Its Impacts On Communication System',University of North Texas.

[13] A. R. Rahimi, A. R. Holt, G. J. G. Upton,S. Krmer, A. Redder, and H-R Verworn-'Attenuation Calibration of an X-band Weather Radar using a Microwave Link',Institute of Water Resources Management.

[14] A. Berne and R. Uijlenhoet(2007)-'Path-averaged rainfall estimation using microwave links: Uncertainty due to spatial rainfall variability',Geophysical Research Letters, Vol. 34, L07403.

[15] Parshotam Sharma, I.S. Hudiara, M.L.Sigh-'Rain Attenuation Statistics over terrestrial Microwave Link operating at 28.75 GHz over Amritsar, INDIA(Tropical Region)',Guru Nanak Dev University.

[16] J. S. Ojo and M. O. Ajewole(2008)-'Rain Rate And Rain Attenuation Prediction For Satellite Communication in Ku and Ka Bands Over Nigeria',Progress in Electromagnetic Research B Vol.5.

[17] Frank Silvio Marzano and Laura Roberti (2003)-'Numerical Investigation of Intense Rainfall Effects on Coherent and Incoherent Slant-Path Propagation at K-Band and Above',IEEE Transactions On Antennas And Propagation, Vol. 51, No. 5.

[18] V. N. Bringi, T. D. Keenan, and V. Chandrasekar(2001)-'Correcting C-Band Radar Reflectivity and Differential Reflectivity Data for Rain Attenuation: A Self-Consistent Method With Constraints',IEEE Transactions On Geoscience And Remote Sensing, Vol. 39, No. 9.

[19] Glenn S. Feldhake and Dr. Lynn Ailes-Sengers(2002)-'Comparison of Multiple Rain Attenuation Models with Three Years of Ka Band Propagation Data Concurrently Taken at Eight Different Locations',Stanford Telecommunications, Inc..

[20] Robert K. Crane (2003)-'A Local Model for the Prediction of Rain-Rate Statistics for Rain-Attenuation Models',IEEE Transactions On Antennas And Propagation, Vol. 51, No. 9.

[21] Y.Y. Shan, J.T. Ong, Y.H. Lee, and T.T. Nguyen(2005)-'Lognormal model for Singapore raindrop size distribution',0-7803-9282-5/05/$20.00 2005 IEEE.

Websites

[22] $http : //www.watershedatlas.org/fs_indexwater.html$

[23] $http : //www.tulane.edu/\ sanelson/geol204/riverflooding.htm$

[24] $http : //en.wikipedia.org/wiki/Breadth - first_search$